POTASSIUM METABOLISM IN THE OVINE

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ABSTRACT

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Two 30-day balance trials, a 56-day feeding trial, a 56-day paired feeding trial, and an appetite trial were conducted to study the role of potassium in ovine nutrition. Western range wether lambs were used in the experiments. A semi-purified ration consisting of brewers grains, corn starch, solka floc and animal tallow was used in the balance study. A similar ration was used in the feeding trials. Levels of potassium fed were 0.7, ("low"), 2.2 ("medium") and 3.7 ("high") g per day in the balance study and 0.1, 0.3, 0.5 and 0.7% of the ration in the feeding trials.

The data suggest that the optimal ration level of potassium for fattening lambs is between 0.3 and 0.5% of the air dry ration. The 0.5% treatment exhibited an average daily gain of 0.37 lb per day in contrast to 0.06 lb per day for the 0.3% lambs. The 0.1% level resulted in a marked decrease in feed consumption, a loss of weight, listlessness, pica, damage to the kidney and a decrease in non-scoured wool potassium concentrations. A paired feeding trial revealed an effect of potassium on growth as lambs consuming a 0.7% potassium ration

gained significantly ($P < 0.05$) more weight than lambs consuming the same quantity of a 0.3% potassium ration.

Serum potassium and phosphorus concentrations of the 0.1 and 0.3% potassium lambs were significantly lower than those of the other groups. On the other hand, there were no significant differences among treatments in serum levels of sodium, calcium, magnesium or chloride. However, when lambs were pair fed the 0.3 and 0.7% potassium rations no differences in serum phosphorus levels were observed but the serum calcium concentrations of the 0.3% lambs was significantly higher than those of the 0.7% lambs.

Potassium depletion resulted in decreased potassium concentrations in skeletal and heart muscle and an increase in liver potassium. An increase in skeletal muscle sodium levels was observed while the heart muscle sodium concentration decreased.

Apparent potassium balance was significantly lower for the "low" potassium lambs than for the other treatment groups. The balance data indicate that the potassium maintenance requirement of wether lambs is less than 2.2 g per day. Level of potassium in the ration had an effect on sodium retention causing an increased urinary excretion when 0.7 g potassium per day was fed and a lower net absorption when 3.7 g potassium per day was fed.

Nitrogen balance was less positive for the "low" potassium lambs; however, level of potassium intake had no effect on apparent nitrogen digestibility. Similarly, apparent digestibilities of dry matter and energy were not affected by treatment.

The marked appetite effect observed in the lambs receiving low potassium rations did not appear to be mediated via the microorganisms since microbial activity, as measured by an *in vitro* technique, was not affected by the treatment levels of potassium.

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INTRODUCTION

Potassium is the major intra-cellular cation in animals and as such plays a prominent role in metabolism. It is intimately involved in enzyme systems which function in carbohydrate and protein metabolism. In addition, potassium functions in body electrolyte balance, osmosis and muscle contraction. Potassium is not stored to any great extent in the body thus a certain quantity must be fed to prevent body depletion and subsequent cellular disfunction. In fact Muntwyler *et al.* (35) have stated that:

"As long as there is a flow of urine the body apparently will continue to lose potassium unless the element is replenished by the diet."

Most natural feeds contain an abundance of potassium. However, because of the use in recent years of experimental purified rations and also all concentrate rations for beef cattle and sheep, a definition of their potassium requirement is imperative. Considerable work has been done with rats, mice, chickens and turkeys in regard to dietary potassium requirement. In contrast to this the potassium requirement of fattening lambs has not been definitely defined and there is a paucity of information concerning the metabolic role of potassium in ruminants. Consequently, it was the objective of this study to ascertain the role of potassium in ovine nutrition and to determine the requirement of fattening lambs for this mineral element.

LITERATURE REVIEW

Role of Potassium Within the Animal Body

Potassium and sodium are the major monovalent cations found within the body and a discussion of one must automatically include the other. Potassium exists mainly in the cellular fluid while sodium is a major extra-cellular cation. The relationship between these two ions has been a focal point of interest for many years. The concept of tissue cell walls being impermeable to these cations has been disproven by isotope techniques (6). More recent theories concerning behavior of these ions include a "sodium pump" mechanism and intra-cellular binding of potassium (6, 26). In the "sodium pump" concept energy is required for active transport of sodium out of the cell and in "potassium binding" energy is also required for the formation of the poorly ionized salt, potassium glucose diphosphate. Since these cations form a major portion of the ionic equivalents within the extra- and intra-cellular phases, they perform a very import role in maintaining osmotic balance and electrical neutrality. Similarly, sodium and potassium are intimately involved in the buffering system within the body.

Metabolically, potassium functions in many enzyme systems. Among the enzymes for which potassium has been found to be important are; phosphotransacetylase, acetyl CoA synthetase, pantothenate synthetase, pyruvate phosphokinase and myosin ATP-ase (6). The demands of osmolarity and electroneutrality, caused by a depletion of potassium, result in an increased entry of sodium into the cells. Black (6) has suggested that, since sodium is antagonistic to the potassium effect on enzyme systems, the consequences of intra-cellular depletion of potassium may be partially due to the increase in cellular sodium concentration. *In vitro* and *in vivo* studies have shown that such depletion also results in irregularities in intermediary metabolism, particularly carbohydrate and protein synthesis (43).

Utilizing *in vitro* experiments Fenn (20) showed that deposition of glycogen in the liver is accompanied by deposition of potassium. Further, Asford and Dixon (1) demonstrated that anaerobic glycolysis was inhibited and aerobic glycolysis stimulated by the addition of potassium to a medium of incubating rabbit brain slices. Similarly, Hastings quoted by Welt *et al.* (43) reported a decreased glucose uptake, increased glucose output and a decreased glycogenesis when rat liver slices were depleted of potassium. However, studies with intact animals have produced inconsistent results regarding the relationship between carbohydrate metabolism and potassium intake. Contrary to the liver slice experiments of Hastings and coworkers potassium depletion has been shown to result in increased liver glycogen levels in rats (22). On the other hand, another report indicated glycogen was practically absent in rats deprived of potassium for 90 to 120 days (23). However, as suggested by Welt et al. (43), the apparent contradiction in these two reports regarding liver glycogen in rats may be explained by a decreased liver glycogen in the latter case mediated by starvation as poor appetite is associated with potassium deprivation.

In many of the earlier studies involving potassium metabolism a decrease in growth was found to be associated with potassium deficiency. Later studies suggest that this decreased growth rate is related to protein metabolism. Cannon et al. (11) subjected rats to a protein depletion diet until they lost 20 to 30% of their initial weight. After depletion two groups, of 10 depleted rats each, were fed a basal ration adequate in all respects except for potassium, and an amino acid solution. One group received potassium and the other no potassium. Weight gains and feed consumption were recorded, and although feed intake was quite similar, the group receiving no potassium supplementation gained 25% less weight than the group receiving potassium supplementation. This data suggests that potassium had an effect upon protein anabolism. Similar results were reported by Muntwyler et al. (35) who compared rats consuming rations both adequate and low in potassium. Rats consuming the low potassium ration exhibited poor growth and lower nitrogen retention both before and after realimentation with protein. Muntwyler _et al._ (35) suggested that, since nitrogen intake of the potassium deficient rats was approximately equal to controls, there was impaired nitrogen anabolism as a consequence of potassium deficiency.

Consequences of Potassium Depletion

It is important at this point to make clear what is meant by a deficit or depletion of potassium. Scribner and Burnell cited by Welt _et al._ (43) developed the concept of potassium "capacity". As the potassium within the cells is intimately related to protein and glycogen the quantity of these two is the major determinant of the potassium "capacity". Consequently, a cell deficit of potassium would not become apparent if glycogen and protein were lost along with potassium. Burnell and Scribner (9) claim that at any given level of total body potassium, there is an inverse relationship between serum pH and serum potassium concentration. Thus as the manifestation of a potassium deficit is complicated by many factors it is not unreasonable that, as reported by Welt _et al._ (43), the correlation between a potassium deficit and its level in serum is poor when the deficit is estimated by either muscle analysis or by determination of total exchangeable potassium, utilizing potassium 40. However, Telle *et al.* (41) reported a significant correlation between level of potassium in the ration and serum potassium concentrations in lambs. In addition to serum potassium changes in relation to the potassium capacity, other serum compositional changes during potassium depletion include a frequent but not invariable decrease in chloride (43), a decreased hematocrit (41) and an increase in bicarbonate (43).

Associated with potassium deficiency are anorexia and reduced rate of growth (3, 30, 34, 41). However, paired feeding experiments have shown that the slower rate of growth cannot be completely accounted for by the concomitant reduction in feed intake (11, 31). As mentioned earlier the relationship of potassium to intermediary metabolism may be the factor causing this effect.

Other deficiency symptoms in rats include roughening and thinning of the fur, a striking alertness and a peculiar pica (36). Meyer *et al.* (33) observed similar symptoms when rats were fed low levels of both sodium and potassium. However, when these ions were fed in ratios (Na/K) of 2, 20 and 200 to 1 the rats exhibited listlessness and diarrhea. Although Orent-Keiles and McCollum (36) were able to maintain rats on a low level of ration potassium (0.01% K) for 327 days, Meyer *et al.* (33) observed death within 14 days in rats fed a high ration level of sodium (1.0% Na) and a low ration level of potassium (0.005% K). Similarly, Bell and Eirfle (3) found that mice, fed a semi-purified diet with no supplementary potassium, became emaciated and died after five - six days on test. Brink (8) observed decreased weight gains, emaciation, loss of wool, muscular stiffness and lack of appetite in sheep consuming a ration containing 0.1% potassium. Similar results were reported by Telle et al. (41), and in addition, two deaths occurred among the lambs receiving the lowest potassium ration (0.1% K).

In potassium deficiency there is movement of sodium into the cell to compensate for the decrease in potassium. However, the replacement is not complete and reports show that approximately 2/3 of the potassium lost is replaced by sodium (43). Hydrogen ions have been implicated as the other cation to make up this deficit (14, 35), and also certain basic amino acids have been suggested (19). The end result of these electrolyte shifts is extra-cellular alkalosis and impaired renal function.

A concomitant increase in sodium and decrease in potassium have been observed in skeletal and heart muscle with very little change in kidney tissue during potassium depletion (33, 35, 43). However, data concerning liver electrolyte changes during potassium depletion are not so consistent.

Most workers have reported the liver potassium content to be quite stable with no change despite significant total body potassium deficits (43). In contrast to this, Meyer et al. (33) observed a significant increase in liver potassium concentration of rats maintained on a potassium deficient diet.

Muntwyler et al. (35) reported that an important feature of potassium depletion is its continuous renal loss. A balance study conducted on a healthy 35 year-old man, by Blahd and Bassett (7), substantiates this suggestion. These workers observed a negative potassium balance following the initiation of a potassium depletion trial, and as the trial progressed the urinary excretion of potassium fell to a relatively constant minimal level. This reduction in urinary potassium output was, however, not adequate to prevent loss of potassium from the body and a negative cumulative potassium balance resulted. In contrast to this observation Orent-Keiles and McCollum (36) maintained rats on a potassium deficient diet (0.01% K) for 327 days with the animals being in equilibrium as far as potassium was concerned at the end of the trial.

Muntwyler et al. (35) reported an effect of low potassium intake on the nitrogen balance of rats. A less positive balance was observed in all groups receiving low potassium. In addition, the levels of sodium and chloride in the ration seemed to influence nitrogen utilization. The work of Devlin and Roberts (16) corroborates this sodium effect, as they reported an increased urinary nitrogen excretion by lambs fed a low sodium ration. As mentioned earlier Cannon et al. (11) also reported an adverse effect of low potassium intake on cellular nitrogen utilization.

On reviewing the literature concerned with the pathology of potassium depletion Welt et al. (43) reported that the majority of kidney lesions are of tubular origin and of two types: (1) an intra-cellular accumulation of large granules, and (2) swelling and hyperplasia of the tubular epithelium. The former lesions are found in the inner medulla and papilla and their nature is not definitely known; although Pearse and MacPherson (37) suggested that they might be altered mitochondria. The dilation of kidney tubules commonly observed in potassium deficiency is thought to be caused by the hyperplastic lesions. Telle et al. (41) observed areas of interstitial nephritis and a few hyaline mineralized casts in the kidney collecting tubules of potassium deficient lambs.

Potassium depletion has been shown to result in myocardial lesions in rats (35), mice (43), pigs (43), and cats (15) but not in sheep (41) or dogs (15). Skeletal muscle necrosis has also been reported as a consequence of potassium lack (8, 41).

It has been demonstrated that the ratio of sodium to potassium is very important in potassium deficiency. Meyer *et al.* (33) reported no relationship between structural changes in kidney, thymus, spleen and liver tissues of rats and the levels of sodium and potassium in the ration. On the other hand, the microscopic lesions were observed in heart tissue and they became more severe as the sodium level of the potassium deficient ration was increased. This finding was later substantiated by Cannon *et al.* (12). These workers divided 15 protein depleted rats into three groups: one group received a ration devoid of both sodium and potassium; a second group received supplementary sodium; and the remaining group received both added sodium and potassium. All rats fed the sodium-potassium deficient diet lived and heart lesions were observed in only two of the five rats. In group two, three of the five rats died and severe heart lesions were observed in all the rats. The third group showed optimum growth with no heart lesions developing. In a later experiment these same workers subcutaneously injected protein depleted-potassium deficient rats with 5 ml of a hypertonic sodium chloride solution (4.66%). Death of all rats was observed within 24 hours.

Potassium Requirements

Most natural food stuffs contain sufficient potassium to meet human and other animal requirements. However, the use of purified diets in experimental work and the development of all concentrate rations for ruminants have resulted in considerable interest in the potassium requirement of various species of animals. Orent-Keiles and McCollum (36) reported that a ration containing 0.01% potassium was inadequate to maintain normal growth of rats. Similarly, Miller (34) produced greatly retarded growth rates in rats by reducing the ration level of potassium below 0.1%. Later studies by Kornberg and Endicott (31) indicated that a ration potassium level of 0.17% was adequate to uniformly prevent pathological lesions and promote normal growth in rats. A ration containing 0.2% potassium produced normal growth when fed to mice (3). Graw _et al._ (24), cited by Bell and Eirfle (3), indicated that the chick requires from 0.16 to 0.20% potassium depending on the stage of growth. A slightly higher requirement is displayed by the turkey. Sullivan (40) reported that a potassium ration level of at least 0.275% was necessary for survival of 50% of the turkeys tested. Du Toit _et al._ (18) did not notice any deficiency symptoms when cattle were fed a herbage containing 0.34% potassium. Brink (8) found that a ration containing 0.3% potassium was not adequate for the optimum growth of lambs and that a level of 0.5% was required. On the other hand, Telle *et al.* (41) showed the potassium requirement of lambs for growth to be about 0.3% of the ration. Devlin and Roberts (16) suggested that the potassium requirement for maintenance of wether lambs was 1.2 g per day.

EXPERIMENTAL PROCEDURE

Experiment Ia

A 56-day feeding trial was conducted to study the potassium requirement of fattening wether lambs. Sixty-four western range lambs averaging 74.1 lb each were adjusted to a semi-purified ration consisting of the following ingredients (expressed as per cent): dried brewers grains, 66.9; corn starch, 15; solka floc, 11; animal tallow, 5; dehydrated alfalfa, 1.0; mineral-vitamin supplement, 1.1[1]. The basal ration contained 0.046, 0.15 and 0.12% potassium, sodium and chloride[2], respectively. After an initial 11-day adjustment period the lambs were randomly alloted to four groups of 16 lambs each, and were equilibrated on a 0.5% potassium ration for an additional seven days. Ration potassium levels of (expressed as a per cent of the air dry ration) 0.1, 0.3, 0.5 and 0.7% were made by adding various levels of K_2CO_3 to the basal ration. These ration treatments were randomly assigned to the four groups. At the initiation of the trial feed intake was restricted and then the quantity offered was

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[1]The mineral-vitamin supplement contained the following (expressed in g per lb): dicalcium phosphate 294.2; sodium chloride 159.8; and vitamins A and D to supply 3,000 I. U. and 500 I. U. per day, respectively.

[2]Calculated from values listed in Feeds and Feeding 22nd ed.

gradually increased until *ad libitum* consumption was attained by all treatment groups. The lambs were weighed every two weeks and average daily gains were recorded. Tap water (1.6 ppm potassium) was available *ad libitum* and wood shavings were used for bedding. In the remainder of the text the lambs receiving the various treatment levels of potassium (0.1, 0.3, 0.5 and 0.7%) will be referred to as groups 1, 2, 3 and 4, respectively.

At initiation of the trial, six lambs from each of groups 1 and 3 were randomly chosen and venous blood samples were obtained by the jugular puncture technique. Blood collection at termination of the trial included the 12 above mentioned lambs and, in addition, the remaining lambs in group 1 and six lambs chosen randomly from each of groups 2 and 4. The blood samples were allowed to clot for approximately 2 hours and then were centrifuged at 2200 rpm for 20 minutes. The samples were stored at -18^{o}C until analysed. Wool samples were taken from six lambs chosen randomly from each of groups 2, 3 and 4 and from five lambs that were sacrificed in group 1. These samples were obtained by clipping approximately 30 g of wool from the right front shoulder of each lamb.

Regular observations were made to notice any deficiency symptoms among the lambs and, when any of the lambs were considered in moribund condition, they were sacrificed and an autopsy performed. Autopsies were also performed on three lambs chosen at random from group 1 at the end of the trial. Tissue samples were obtained from four of the group 4 sheep at slaughter and from a total of five lambs in group 1 that were sacrificed. Sections of the skeletal and heart muscles, adrenal gland, kidney, and small intestine were preserved in formalin for slide preparation and histological observation. Approximately 50 g of gluteal and subscapular muscle were removed from the carcass and frozen. In addition, a portion of the liver, an intact kidney and approximately 10 g of heart muscle were removed and stored at -18°C. At slaughter and during the autopsy intact kidneys from each lamb were obtained and, after removal of fat and connective tissue, weighed and then stored at -18°C for later analyses.

On the 15th day of the trial rumen contents were collected from two lambs chosen randomly from each of groups 2 and 4. The samples were obtained by stomach tube and a suction pump. The pH of each sample was immediately determined using a glass electrode type pH meter.

As soon as possible after collection (approximately 60 minutes) duplicate 15 g subsamples of rumen contents from each lamb were transfered to 160 ml Warburg flasks and microbial activity was estimated by a method similar to that of Hungate *et al.* (29). Another portion of each rumen sample was strained through four layers of cheesecloth and the resulting fluid retained for analysis. Dry matter of each rumen sample was also determined. On the following day four different lambs were chosen at random from the same two groups and rumen contents were obtained and treated in the same manner as before.

Experiment Ib

A subsequent 56-day paired feeding trial was conducted utilizing nine of the lambs remaining in group 1. Five lambs were fed the 0.3% potassium ration *ad libitum*, and four lambs were allowed to consume an equivalent weight of the 0.7% potassium ration. The lambs were fed once daily and tap water was consumed *ad libitum*. Venous blood samples were collected after 28 days on test and at termination of the trial. The blood samples were treated as in Experiment Ia. The lambs were weighed every four weeks and daily weight gains were recorded. Rumen samples were collected on the 29th day of the trial from two sheep chosen randomly from each group and treated as in Experiment Ia.

Experiment Ic

The 16 lambs that had received the 0.3% potassium ration in Experiment I were randomly alloted to two groups of eight lambs each. The 0.1% potassium ration was fed ad libitum. Seven days were allowed for adjustment to the lower level of potassium and then the lambs were divided into a control group and a treatment group. An intraruminal injection of 1.5 g potassium as K_2CO_3 dissolved in 10 ml deionized water was administered to the treatment group every three days for 12 days (four injection periods). At this time the quantity of potassium was increased to 10 g per injection and the injections were continued for another 9 days (three injection periods). The control group received an intraruminal injection of 10 ml deionized water every 3 days for the duration of the experiment. After the last injection period both groups were fed a potassium adequate diet (0.5% potassium) for an additional 21 days. Average daily gains and feed consumption were recorded.

Experiment II

Replicate balance trials were conducted using six western range wether lambs per trial. They ranged in weight from 68 to 82 lb. Each trial was divided into an adjustment period, a pre-experimental period and an experimental period. During the adjustment period, which lasted 12 days, the lambs were fed twice each day with a total daily intake of 570 g basal ration (table I), 30 g mineral mix (table I) and 3.5 g potassium as K_2CO_3. The same feeding regime was continued throughout the 3-day pre-experimental collection period. A 30-day experimental period followed in which the potassium levels were changed to 0.5, 2.0 and 3.5 g. The intake of potassium including the amount inherent in the ration was 0.7, 2.2 and 3.7 g per day. Thus, during this experimental period there were two lambs per trial receiving each potassium level. Sodium intake was constant throughout the whole trial and averaged 89.54 mEq/day (3.9 g). Poor appetite was exhibited by the lambs receiving 0.7 g potassium per day, thus in order to maintain a constant mineral intake the amount of basal ration fed was reduced and the quantity of mineral fed held constant. However, if the lambs still refused to consume all the feed offered a weigh back was taken and the amount of mineral not consumed determined. Throughout the remainder of the text these potassium levels will be referred to as "low", "medium" and "high".

Tap water (1.6 ppm potassium) was offered *ad libitum* and the amount consumed was recorded. The lambs were weighed at the beginning and end of the experimental period and the changes in body weight recorded. The daily temperature in the metabolism area was recorded.

The lambs were kept in metabolism crates which

TABLE 1 EXPERIMENT II

BASAL RATION

Ingredient	Per cent
Brewers grains	67
Corn starch	12
Solka floc (cellulose)	11
Animal tallow	5
Mineral mix*	5

*The mineral mix contained the following (expressed in g per lb): $CaHPO_4$, 236.01; $MgSO_4$, 124.15; NaCl, 57.66; $FeSO_4$, 12.24; $MnSO_4$, 11.44; KI, 6.82; $ZnSO_4$, 5.46; $CuSO_4$, 0.19; MoO_3, 0.009; $CoCl_2$, 0.005; and vitamins A and D to provide 2000 I.U. and 500 I.U., respectively, per day. In addition, K_2CO_3 was added at levels to supply 0.7, 2.2 and 3.7 g potassium per day.

allowed separate collection of urine and feces. The feces were removed and weighed daily and stored at -18°C. Aliquot samples from six consecutive daily fecal collections were combined, by thawing and mixing in a Hobart mixer, and retained for analysis. Urine was collected by means of a rubber urinal which was drained by a 5/16 inch rubber hose into a glass collection jar located below the metabolism crate. The urinal was secured by a small harness fitted to the sheep. In addition, a small weight was attached to the urinal to hold it in place and also assure rapid drainage of urine from the urinal. The urine was collected under toluene and the total quantity excreted each day was recorded. Approximately 50 ml of each daily sample were removed and immediately frozen. After six consecutive daily urine samples had been collected, they were removed from the freezer and aliquot composites made. Blood was collected on the 1st, 15th and 30th days of the experimental period. The samples were treated as in Experiment Ia. Rumen samples were collected from three of the lambs on the 31st day of the experimental period (one per treatment) and from the remaining three lambs the following day. All rumen samples were collected approximately 90 minutes after the morning feeding and were treated as in Experiment Ia. At termination of the trial, wool samples were obtained as in Experiment Ia and retained for analysis.

Analytical Methods

The feed, feces, urine, wool, tissue, rumen fluid, and serum samples were analysed for sodium and potassium by flame photometry, using an internal standard method as described by Berry *et al.* (4). However, a bracketing technique, instead of a standard curve, was used for determination of the concentrations of these two ions. Lithium sulfate (300 ppm) was used as the internal standard.

Approximately 0.6 g of dried feces and feed were digested in micro-Kjeldahl flasks for sodium and potassium analyses. Concentrated nitric acid and 70% perchloric acid were used to digest the organic matter. After digestion the samples were filtered through Whatman #40 filter paper and made to known volumes with deionized water. Various dilutions were necessary in order to obtain concentrations of sodium and potassium that would be within an estimated pre-determined range. The crude wool samples were analyzed in a similar manner. The tissue samples were extracted with ether for 4 hours and the dried fat-free samples were digested by the same procedure as used for the feed and feces.

For sodium and potassium analyses of urine and serum the samples were diluted, according to approximate concentration of the two ions, and analysed directly in the flame photometer. The samples of rumen fluid were analysed in a similar manner.

Total nitrogen was determined in feed, feces and urine samples using the Kjeldahl method described by A.O.A.C. (2). Two ml of fresh urine were used for analysis. The feed and feces samples were dried at 70°C for 60 hours and then allowed to equilibrate at room conditions. The samples were then ground in a Wiley mill and approximately 1 g of ground sample was used for analysis.

Urine ammonia and urea were determined by an aeration method (Van Slyke and Cullen modified) described by Hawk *et al.* (27). The six-day composite samples were analysed as soon as possible after collection. One ml of undiluted urine was used for the ammonia determination and 5 ml of urine, diluted to 1:20 with distilled water, were used for the urea analysis.

Urinary creatinine and creatine were determined using the method of Biggs *et al.* (5). The daily urine collections were kept frozen and the analysis carried out at the end of each 6-day collection period.

Dried feed and feces samples from the fourth 6-day collection period in each trial were combusted in a Parr adiabatic oxygen bomb calorimeter. Apparent digestible energy was determined for each ration using the total collection method (32). In addition, apparent dry matter digestibility was calculated for the same period. Apparent digestible nitrogen values were calculated for the total 30-day experimental period.

Serum chlorides were determined by the method of Schales and Schales (38). In addition, serum inorganic phosphorus was determined by the method of Fister (21) and total serum calcium and magnesium according to the method of Walser (42).

Statistical methods used were analysis of variance, t-test and Duncan's multiple range test as described by Steel and Torrie (39).

RESULTS AND DISCUSSION

Experiment Ia

Effect of Potassium Intake on Feedlot Performance. Level of potassium in the ration had a marked effect on feedlot performance of the lambs (table 2). Average daily weight gains were significantly ($P< 0.01$) lower in groups 1 and 2 than in groups 3 and 4. The group 3 and 4 sheep gained an average of 21.0 and 21.3 lb, respectively, over the 56-day period while the group 2 lambs gained only an average of 3.0 lb and the group 1 lambs lost, on the average, 16.9 lb. As is evident from the standard errors presented in table 1, there was considerable variation among groups in response to the two lower levels of potassium. These data indicate the potassium requirement of feedlot lambs to be between 0.3 and 0.5% of the air dry ration. Brink (8) added various levels of KCl to a semi-purified ration and found a ration potassium level of 0.5% to be adequate. Contrary to this Telle *et al.* (41) later reported nearly optimum growth by lambs consuming a basal ration somewhat similar to that used in the present study and containing 0.3% potassium. However, these workers suggested 0.5% potassium as the optimum level of ration potassium.

Appetite seems to be markedly altered by an inadequate intake of potassium. Feed consumption of the group 1 lambs dropped sharply within two days after beginning the trial. This appetite effect, although not as severe, was also apparent in lambs consuming the 0.3% potassium ration. They did not consume their feed as rapidly as groups 3 and 4 and by the 6th day of the experiment were beginning to leave a portion of the feed offered. The average daily feed consumption during the experimental period (table 2) reveals a very drastic effect of ration potassium on feed consumption. Daily feed consumption of the group 1 lambs was less than half that of the group 2 lambs and less than one third that of the two groups receiving the higher levels of potassium. The wide variation in weight gains (18 lb gain to 17 lb loss in group 2 lambs) indicates considerable individual variation with regard to this appetite syndrome. However, the fact that potassium was fed as a percentage of the ration may account for some of this variation. Each reduction in feed intake caused by the low level of potassium in the ration would tend to aggrevate this condition, resulting in a progressively smaller total intake of feed and consequently potassium.

Average values of 0.017 and 0.027 mEq potassium per ml of rumen fluid and 0.101 and 0.106 mEq sodium per ml of rumen fluid were found in the rumen samples obtained from the group 2 and group 4 lambs, respectively. The sodium to potassium

TABLE 2 EXPERIMENT Ia

EFFECT OF RATION POTASSIUM LEVEL UPON GROWTH AND VARIOUS SERUM COMPONENTS IN LAMBS

Item	Treatment 1	Treatment 2	Treatment 3	Treatment 4
Ration potassium %	0.1	0.3	0.5	0.7
Number of lambs	16	16	16	16
Av daily gain, lb	$-0.33^{A} \pm 0.041$	$0.06^{B} \pm 0.50$	$0.38^{C} \pm 0.025$	$0.37^{C} \pm 0.027$
Av daily feed, lb	0.84	1.92	2.64	2.71
Av daily feed/lb gain, lb	-----	35.17	7.02	7.24
Serum potassium, mEq/l	$3.37^{A} \pm 0.11$	$4.11^{A} \pm 0.29$	$4.61^{B} \pm 0.15$	$4.84^{B} \pm 0.13$
Serum sodium, mEq/l	146.8 ± 1.34	152.6 ± 2.33	151.9 ± 1.65	151.6 ± 2.4
Serum chloride, mEq/l	114.4 ± 1.37	113.9 ± 2.26	112.5 ± 2.36	109.8 ± 0.96
Serum calcium, mg/100 ml	10.71 ± 0.15	10.88 ± 0.58	10.15 ± 0.32	9.77 ± 0.48
Serum magnesium, mg/100 ml	1.90 ± 0.07	2.08 ± 0.26	2.38 ± 0.19	2.32 ± 0.15
Serum phosphorus, mg/100 ml	$6.64^{A} \pm 0.49$	$7.62^{A} \pm 0.17$	$8.79^{AB} \pm 0.31$	$9.86^{B} \pm 0.24$
Non-scoured wool potassium mg/g	$33.99^{a} \pm 5.79$	$37.88^{a} \pm 3.46$	$55.81^{b} \pm 4.21$	$49.97^{ab} \pm 7.38$

[1]Standard error

[A,B,C]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.01$)

[a,b]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

ratios were: group 2, 6.03; and group 4, 3.97. Hubbert et al. (28) reported a decrease in *in vitro* cellulose digestion with a high sodium to potassium ratio. Despite the differences in Na:K ratios observed in this experiment there was no significant ($P > 0.05$) difference in microbial activity of rumen contents from lambs receiving these two rations. The average microbial activity values for groups 2 and 4 were 25.3 and 17.1 mm Hg per g dry matter per two hours, respectively. The pH of rumen contents was quite similar in both groups with average values of 6.4 for group 2 and 6.45 for group 4. Telle et al. (41) suggested that the decreased rate of growth by sheep receiving a 0.1 or a 0.2% potassium ration may have been a consequence of decreased microbial action and/or number of rumen microorganisms. The results obtained in this experiment do not necessarily substantiate this argument but indicate a more direct effect of potassium on appetite and a subsequent decreased growth rate.

Deficiency Symptoms. The lambs in group one exhibited poor appetite, listlessness, and became emaciated. A peculiar pica which involved biting of wool was observed among the group 1 and 2 lambs. This wool biting was quite severe among the group 1 lambs and several of the weaker lambs were almost devoid of wool at termination of the trial. The general deficiency symptoms are similar to those reported by Telle *et al.* (41) and Brink (8) in sheep. Similar symptoms have also been reported in other species of animals (3, 30, 36). By the 56th day of the experiment many of the group 1 lambs were very weak and three death losses[3] had occurred. The first lamb died on the 11th day of the experiment and the remaining two lambs died at 44 and 53 days after initiation of the trial. No deaths occurred in lambs receiving the higher levels of potassium.

Serum, Wool and Tissue Analyses. Level of potassium in the ration did not significantly ($P > 0.05$) affect the serum levels of calcium, chloride, magnesium or sodium (table 2). However, serum potassium and phosphorus levels were significantly ($P < 0.01$) decreased. Since there is a gross relationship between a body deficit of potassium and serum potassium levels, the lower serum potassium levels in groups 1 and 2 were expected. The reason for the difference in serum phosphorus levels is more obscure, although feed intake may be a factor as the lambs in group 1 were only consuming 0.8 lb

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[3]The lambs were destroyed *in extreminis*.

of feed per day in comparison to 2.64 and 2.71 lb per day by groups 3 and 4, respectively. Evidence for this suggestion in ruminants has been reported by Greaves et al. (25) and Wise et al. (44), in that an efficient mechanism for the regulation of serum phosphorus levels is not present in the bovine since there is a close correlation between phosphorus intake and the inorganic phosphorus of the blood. Although the change is not significant ($P > 0.05$) there appears to be a slight but consistent increase in serum calcium with a decrease in potassium intake. The afore mentioned serum patterns are similar to those reported by Telle et al. (41) except that the plasma potassium levels reported by these workers were slightly higher than the present values. Telle et al. (41) suggested that a blood plasma potassium level below 12 mg % may be an indication of inadequate potassium intake. However, comparable serum values in this experiment were 13.25 and 14.90 mg % for the group 1 and 2 sheep, respectively, and these groups exhibited signs of potassium deficiency. This discrepancy may be due to the wide variation in serum potassium levels found both among and within breeds of sheep (13).

Non-scoured wool potassium concentrations are presented in table 2. This data indicates a considerable loss of potassium via the skin in sheep. The potassium loss varies with potassium intake, as lambs in group 3 contained significantly ($P<0.05$) more potassium in the non-scoured wool than those in either groups 2 or 1. Telle et al. (41) also found the skin of sheep to be a major excretory route for potassium, with an increased excretion when potassium intake was increased. It is apparent from the work of Burns et al. (10) that the majority of potassium is adhered to the wool and not a component of the fibers. These workers reported scoured wool potassium concentration of 40 ppm in contrast to a potassium concentration in wool grease of 6,750 ppm and a potassium concentration of 187,500 ppm in suint.

Table 3 represents sodium and potassium tissue concentrations from normal and potassium deficient sheep. There were no significant ($P>0.05$) differences in sodium and potassium concentration of skeletal muscle between the potassium deficient and normal lambs. However, there was a trend toward lower potassium levels and higher sodium levels in the tissues obtained from the deficient lambs. A wide variation in the degree of potassium deficiency among the five lambs from group 1 was observed; thus statistically significant skeletal muscle sodium and potassium levels were not apparent, although three of the five lambs had markedly decreased potassium and increased sodium concentrations. Heart muscle, on the other hand, showed a significant ($P<0.05$)

TABLE 3 EXPERIMENT Ia

SODIUM AND POTASSIUM CONCENTRATIONS[1] OF VARIOUS BODY TISSUES FROM POTASSIUM DEPLETED AND CONTROL LAMBS

	Treatment			
	Sodium		Potassium	
Item	Control	Depleted	Control	Depleted
Gluteal muscle	9.40 ± 0.47[2]	17.18 ± 2.68	38.16 ± 2.08	28.75 ± 4.16
Subscapular muscle	8.42 ± 0.93	15.0 ± 3.70	38.71 ± 1.17	32.39 ± 3.27
Heart muscle	17.12[a] ± 0.65	14.38[b] ± 0.40	34.54[a] ± 0.51	30.48[b] ± 1.14
Liver	8.86 ± 0.49	9.10 ± 0.75	23.80[a] ± 0.62	29.76[b] ± 1.51
Kidney	32.65 ± 2.21	30.98 ± 1.98	27.11 ± 1.66	28.48 ± 1.08

[1]Expressed as mEq/100 g fat-free dry sample

[2]Standard error

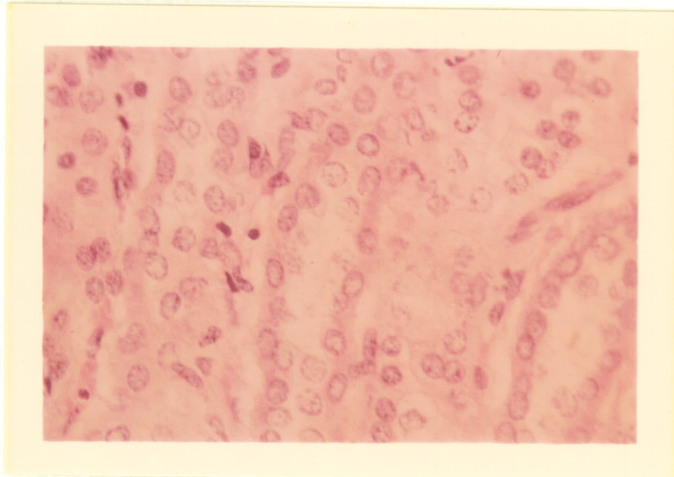
[a,b]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

decrease in both sodium and potassium content when the potassium depleted lambs were compared with the controls. Heart muscle is generally depleted of potassium during potassium deficiency although this depletion is usually less than that for the skeletal muscle (43). Despite the fact that the decrease in skeletal muscle potassium concentration was not significant, the average decrease of 7.65 mEq potassium per 100 g fat-free dry matter was greater than the average decrease of 4.06 mEq potassium per 100 g fat-free dry matter observed in the heart tissue.

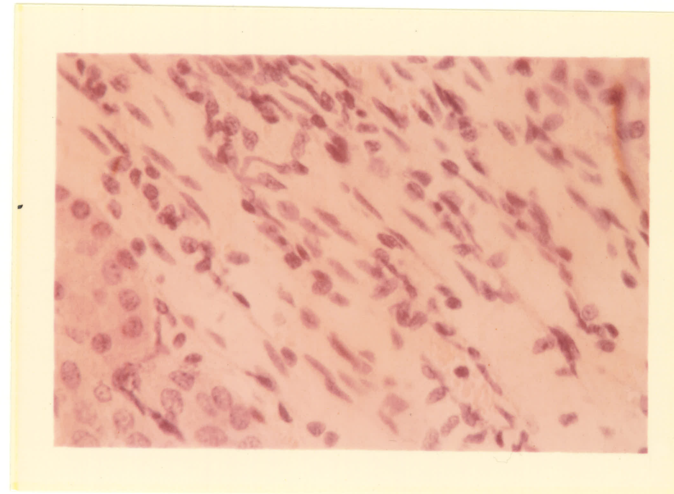
According to most reports (43) sodium is the major cation replacing the cellular potassium lost during potassium depletion. This appeared to be the case in this experiment, as far as skeletal muscle was concerned; however, there was a loss of sodium accompanying the potassium loss in heart muscle. The sodium level in heart muscle of the potassium deficient lambs was 2.74 mEq per 100 g fat-free dry matter less than in heart muscle of normal lambs. Thus it is evident that some other cations were making up the deficit, possibly basic amino acids and hydrogen.

Potassium levels in the liver are generally quite stable and do not share in the potassium depletion during potassium deficiency (43). However, an increased glycogen content in the liver of potassium deficient rats has been reported (35) and, as potassium is associated with glycogen (26), an increase in liver potassium is possible during potassium depletion. The increase would probably be more pronounced if there was a loss of organic matter from the liver without a simultaneous loss of potassium. The results of this experiment tend to substantiate the above hypothesis as there was a significant ($P < 0.05$) increase in potassium concentration per 100 g of fat-free dry liver in the potassium deficient lambs. Liver sodium levels were essentially unchanged as were kidney concentrations of sodium and potassium.

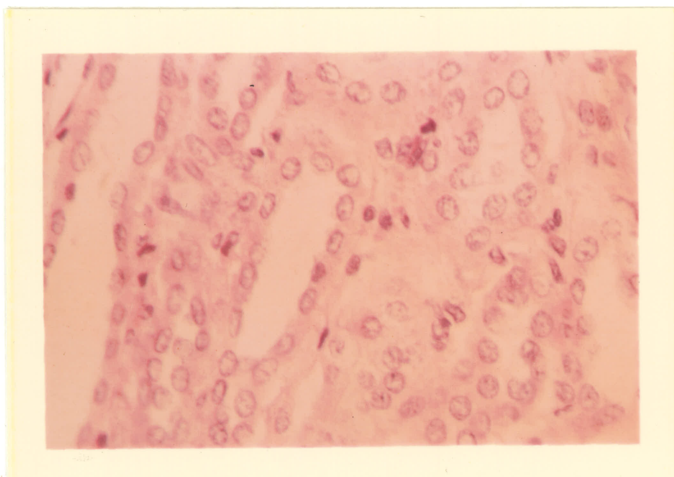
Histological Observations. At autopsy no gross abnormalities were observed among the potassium deficient lambs. Histological study revealed a marked effect of potassium deficiency on the kidney (figure 1). The kidneys from the deficient lambs contained areas of interstitial fibrosis and cloudy swelling of tubules. In addition, hyperplastic lesions and eosinophilic cytoplasmic granules were observed in the tubular area of the kidney. These latter two types of lesions have been observed in other species of animals (43). Many mitotic figures of cells in the collecting tubules were also noticed. The histological observation of the heart, adrenal gland and intestine revealed



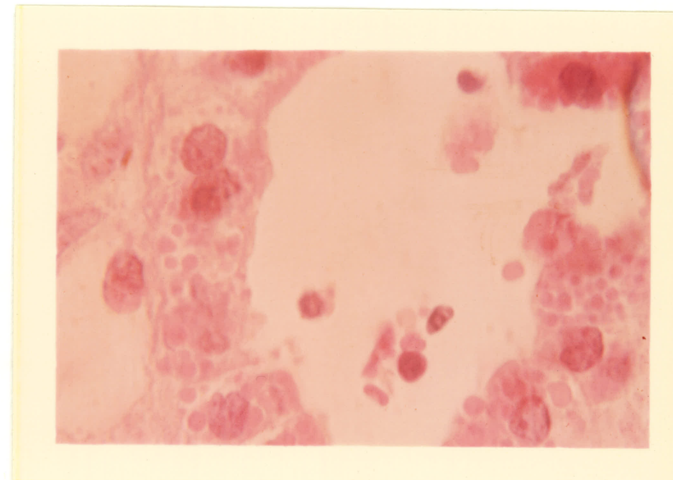
(a) Normal kidney



(b) Interstitial fibrosis

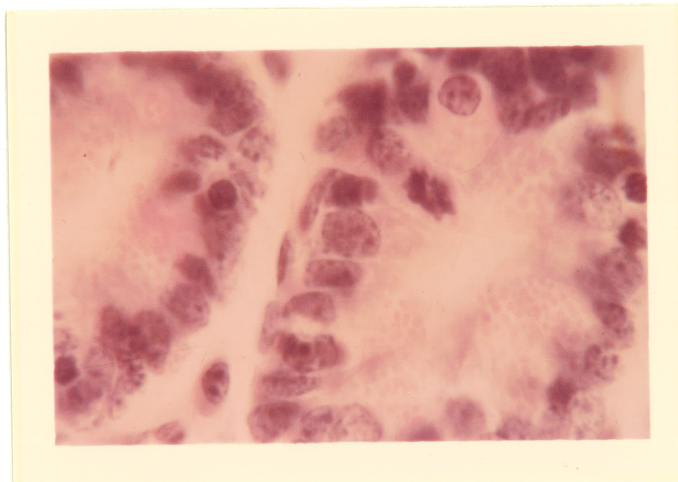


(c) Eosinophilic cytoplasmic granules in kidney tubules (lamb 1)

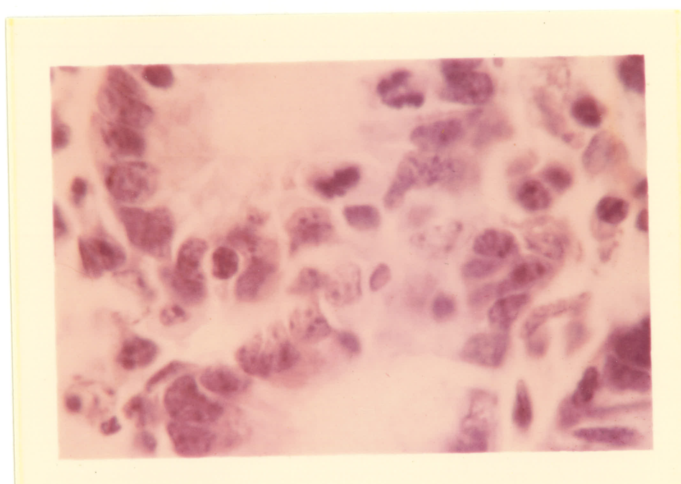


(d) Eosinophilic cytoplasmic granules in kidney tubules (lamb 2)

Figure 1. Kidney sections from normal (a) and potassium depleted lambs (b, c, d, e, f)



(e) Eosinophilic cytoplasmic granules in kidney tubules (lamb 3)



(f) Mitotic figures

Figure 1 (continued)

no marked difference between deficient and control animals. The kidney weights of the depleted lambs, when expressed as a per cent of body weight, were significantly ($P < 0.01$) greater than those of the normal animals. The depleted kidneys averaged 0.37% of body weight as compared to 0.29% for the control kidneys. An increase in kidney size in experimental potassium depletion is common and it has been suggested that, as the ratio of desoxyribonucleic acid phosphorus to fat-free dry solids was the same as that of pair fed controls, the renal enlargement is due to true hyperplasia (43).

Experiment Ib

A great deal of credence cannot be placed on the results from this experiment because of the small number of lambs used. However, lambs consuming the 0.7% potassium ration gained significantly ($P < 0.05$) more weight than lambs receiving an equivalent weight of the 0.3% potassium ration (table 4). Similar results have been obtained with other species of animals (31, 33, 35). The rumen fluid pH and the microbial activity data in this experiment were quite similar to those in Experiment Ia. Thus the results of this experiment indicate that the effect of a low level of potassium in the ration is more than just a reduction in feed intake. The relationship between body potassium and intermediary

TABLE 4 EXPERIMENT Ib

THE EFFECT OF RATION POTASSIUM LEVEL UPON GROWTH AND VARIOUS SERUM COMPONENTS IN PAIR FED LAMBS

Item		Treatment 1	Treatment 2
Ration potassium, %		0.3	0.7
Number of lambs		5	4
Av daily gain, lb		0.23[a]	0.36[b]
Av daily feed, lb		1.48	1.52
Serum potassium, mEq/l	1*	4.13[A] ± 0.21[1]	5.08[B] ± 0.21
	2**	3.23[A] ± 0.13	4.35[B] ± 0.17
Serum sodium, mEq/l	1	151.0 ± 2.24	153.3 ± 1.41
	2	145.0[a] ± 3.95	152.8[b] ± 2.22
Serum chloride, mEq/l	1	113.9 ± 2.57	111.6 ± 0.45
	2	115.6 ± 3.95	113.6 ± 2.13
Serum calcium, mg/100 ml	1	10.69[a] ± 0.22	9.56[b] ± 0.56
	2	10.45[a] ± 0.47	9.53[b] ± 0.44
Serum magnesium, mg/100 ml	1	2.25 ± 0.13	2.39 ± 0.19
	2	2.25 ± 0.55	2.06 ± 0.07
Serum phosphorus, mg/100 ml	1	7.30 ± 0.45	9.07 ± 1.29
	2	8.14 ± 0.51	9.27 ± 0.75

*Samples collected 28 days after initiation of trial
**Samples collected 56 days after initiation of trial

[A,B]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.01$)

[a,b]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

[1]Standard error

metabolism may be a partial explanation, since the efficiency of protein utilization and certain enzyme systems is greatly reduced in potassium depletion (5, 11, 35).

The effect of ration potassium level on various serum components when feed intake was held constant is shown in table 4. Serum potassium and sodium were significantly ($P < 0.05$) decreased by the lower potassium intake while serum calcium concentration was significantly ($P < 0.05$) increased. Phosphorus, magnesium and chloride levels in the serum were similar in both treatments. In Experiment Ia serum phosphorus levels were decreased with a decrease in potassium intake; however, in Experiment Ib where feed consumption was similar this decrease was not observed. This finding substantiates the suggestion from Experiment Ia that serum phosphorus levels are closely related to intake. Serum calcium levels also followed the same pattern as in Experiment Ia. The average of 10.57 mg % for the 0.3% potassium sheep was significantly ($P < 0.05$) greater than the average value for the 0.7% potassium sheep (9.55 mg %). The reason for this increase in calcium is not clear; however, this divalent cation may be increasing to compensate for the loss of serum potassium. A significant ($P < 0.05$) decrease in serum sodium levels was apparent only during the last collection period. Thus one might suggest that, over the prolonged period of low potassium intake, a portion of the extra-cellular sodium moved into the cellular space to correct electrical and osmotic disturbances caused by a depletion of potassium.

Experiment Ic

The average daily feed consumption for lambs receiving a ruminal injection of 1.5 g potassium every three days was 0.81 lb compared to a value of 1.11 lb for the control group. Feed consumption was reduced to 0.23 lb per day by the treatment group when the ruminal injections of potassium were increased to 10 g potassium every three days. The control group was consuming an average of 0.89 lb feed per day during this same period. However, during a recovery period when both groups were fed a ration containing 0.5% potassium, feed consumption rose to double the previous values with the control group consuming an average of 2.16 lb per day and the treatment group 2.05 lb per day. Throughout the injection periods the treatment group lost an average of 0.48 lb per day in comparison to an average daily weight loss of 0.33 lb for the control group. Weight gains for the treatment and control groups during the recovery period were 0.75 and 0.71 lb per day, respectively.

The reason for the low feed consumption of the treatment group was obscure but subsequent work (Roberts and Campbell, unpublished data) has shown that the injection of the concentrated K_2CO_3 solution caused erosion of the rumen epithelium. This erosion probably was the main factor causing the poor appetite in the treatment lambs. However, the exact relationship between potassium and appetite is not clear and requires further study.

Experiment II

Pre-experimental Period. During the 3-day pre-experimental period the 12 lambs retained an average of 10.25 g nitrogen. Eleven of these were in positive balance while one lamb showed a negative balance. All 12 lambs were in positive potassium balance with an average 3-day retention of 49.91 mEq per lamb. In contrast to this three of the 12 lambs exhibited a negative balance for sodium during this preliminary period. The average sodium retention was 52.13 mEq per lamb per 3 days. The lamb exhibiting a negative nitrogen balance over this preliminary period was also in negative sodium balance. The fact that this lamb was scouring could probably account for the negative balances.

In sheep a considerable loss of potassium and sodium can occur by way of the skin (41), and in addition, considerable quantities of these elements can enter the rumen via the saliva or by diffusion across the rumen epithelium. Thus in the following discussion most of the emphasis will be placed on the effect of treatment upon urinary and fecal excretion of sodium and potassium. When the term balance is used in the following discussion it has been calculated from intake minus urinary and fecal excretion of the nutrient in question.

Experimental Period. Weight Gains and Feed Consumption. Equivalent feed consumption by all lambs was an objective of this experiment, but was not realized because of poor appetite exhibited by lambs receiving the "low" potassium treatment. This effect was noticed 3, 5, 6 and 10 days after the initiation of the trial in the four different lambs. Overall intake for the four "low" potassium lambs averaged 342.7 g per day compared to 600 g per day for the other two treatment groups (table 5). The "low" potassium lambs lost an average of 9.2 lb over the 30-day period while the "medium" and "high" treatment lambs gained on the average 4 and 4.5 lb, respectively. The body weight changes observed in the "low" treatment lambs were statistically different ($P < 0.01$) than in the "medium" and "high" treatment lambs. No significant differences ($P > 0.05$) were apparent in water consumption by the various treatment groups (table 5). The daily water consumption among all lambs ranged from 0.9 l per day to 2.7 l per day.

TABLE 5 EXPERIMENT II

WEIGHT GAINS AND DAILY FEED, POTASSIUM, SODIUM, NITROGEN AND WATER INTAKE OF "LOW", "MEDIUM" AND "HIGH" TREATMENT LAMBS

	Treatment		
Item	"Low"	"Medium"	"High"
Av initial wt, lb	77.5	74.0	76.3
Av final wt, lb	68.3	78.0	80.8
Av wt change, lb	-9.2^{A}	4.0^{B}	4.5^{B}
Av daily feed consumed, g	342.7	600	600
Av daily potassium consumed, mEq	13.7	56.1	94.4
Av daily sodium consumed, mEq	62.5	89.5	89.5
Av daily nitrogen consumed, mEq	11.6	18.9	18.9
Av daily water consumed, l	1.4	1.3	1.7

^{A,B}Treatment means within the same item not showing the same superscript letter are significantly different ($P < 0.01$)

Potassium. Data illustrating the cumulative 6-day potassium balances are shown in figure 2. All four "low" potassium lambs were in cumulative negative potassium balance for the 30-day experimental period, although the lambs tended to fluctuate from positive to negative balance throughout the trial. Positive potassium balance was exhibited by all lambs in the "medium" and "high" treatment groups. The "low" treatment groups lost an average of 87.84 mEq potassium compared with apparent retentions of 458.42 and 505.43 mEq, respectively, for the "medium" and "high" treatment groups. During the first 6-day collection period all lambs on the "low" treatment showed a considerable excess in potassium excretion over intake. This excessive loss of potassium from the body was markedly reduced during the second 6-day collection period, and three of the lambs were in positive potassium balance during this second period. Devlin and Roberts (16) reported a similar large negative potassium balance when lambs were abruptly changed from a ration containing 122 mEq to one containing 30.5 mEq potassium per day. These data indicate that lambs require a short period of time to physiologically adjust to a low potassium intake. Although this compensation did occur in the "low" treatment lambs it was not sufficient to prevent a net loss of potassium from the body over

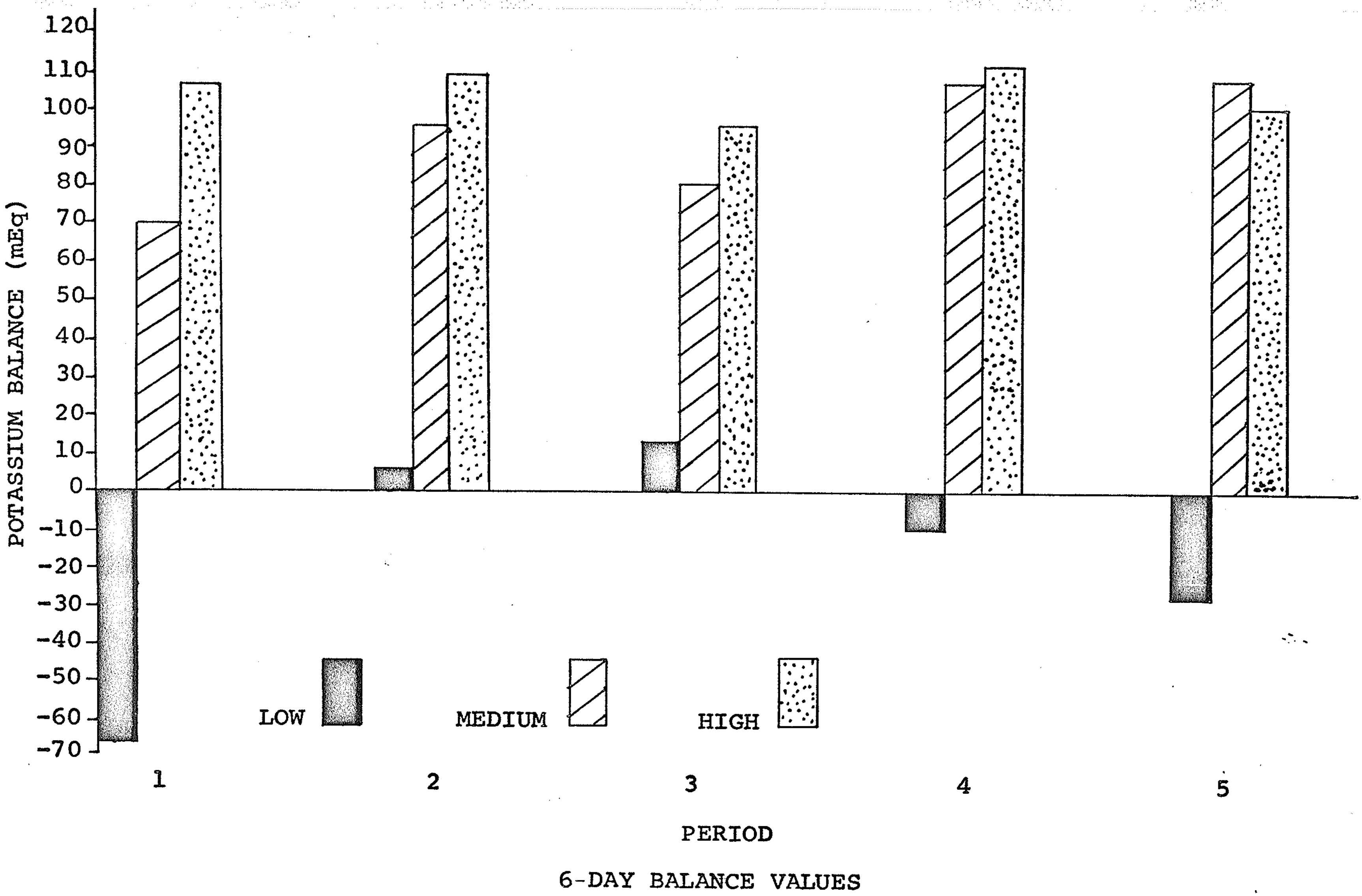


Figure 2. The influence of potassium intake upon apparent potassium balance of lambs receiving 0.7 (low), 2.2 (medium) and 3.7 (high) g potassium daily.

the 30-day period.

Urinary and fecal excretion of potassium during the five 6-day periods are illustrated in figure 3. The average daily excretion of potassium in the urine and feces was lowest for the "low" potassium lambs and then increased as higher levels of potassium were fed (table 6). Urine values for the "low", "medium" and "high" treatment groups were 9.26, 25.78 and 51.03 mEq potassium per day, respectively. The urinary excretion of the "low" treatment group, expressed as a per cent of intake, was significantly ($P<0.05$) greater than the "medium" and "high" groups. There was no statistical difference ($P>0.05$) between the "medium" and "high" treatment groups. Feces excretion for the three treatments were 7.39, 16.69 and 26.55 mEq potassium per day. When expressed as a per cent of intake fecal potassium excretion by the "low" treatment group was significantly greater ($P<0.01$) than by either the "medium" or the "high" treatment groups, which were quite similar. This suggests that net absorption of potassium was not as efficient in the "low" treatment sheep. Intestinal absorption of potassium is a consequence of physical processes such as filtration, diffusion and osmosis (17). Thus it appears that at or below a certain level of potassium intake a constant quantity of potassium is excreted in the feces which results in impaired retention.

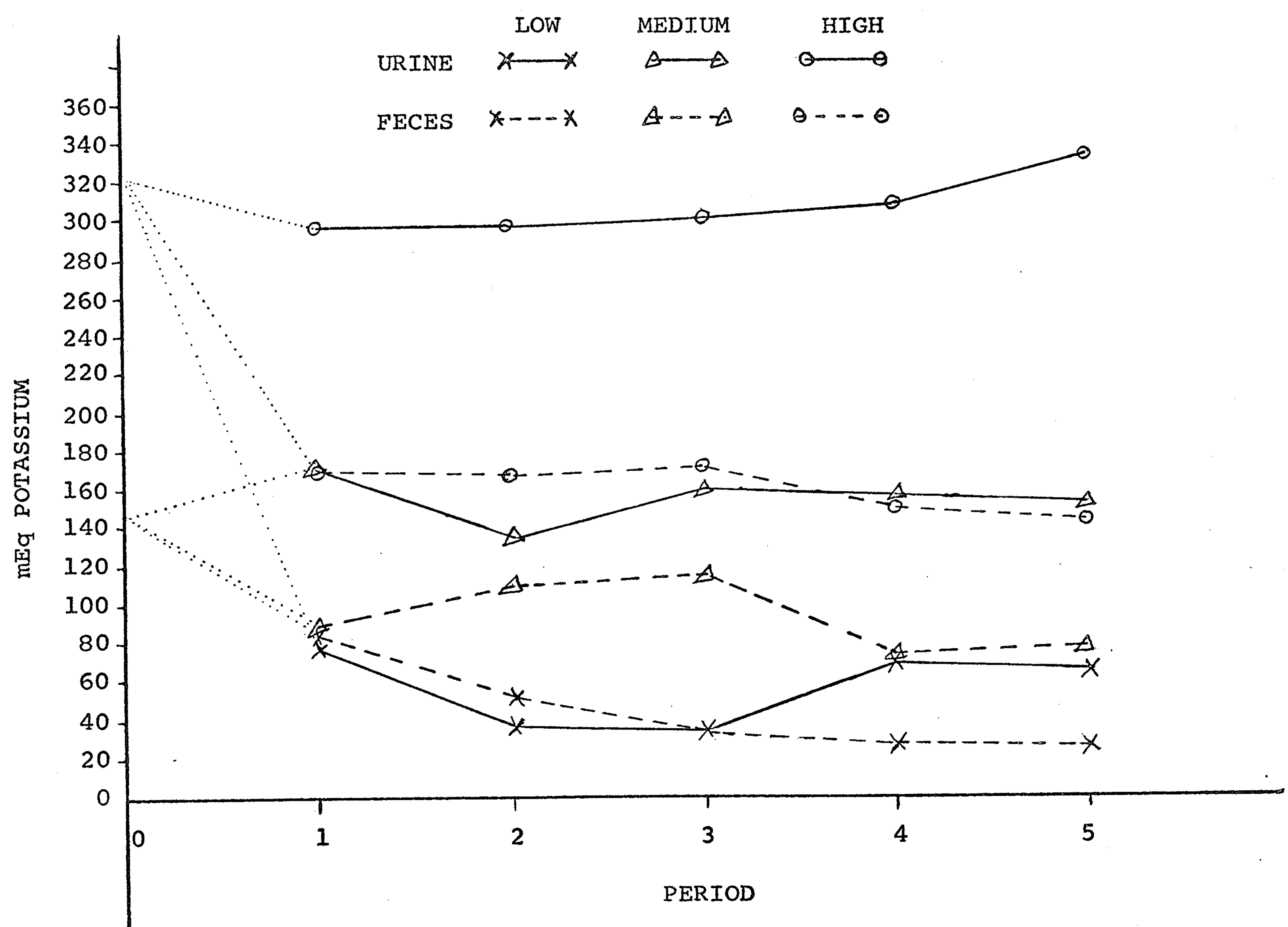


Figure 3. Average 6-day values for urinary and fecal potassium excretion.

TABLE 6 EXPERIMENT II

AVERAGE DAILY EXCRETION OF POTASSIUM, SODIUM AND NITROGEN IN FECES AND URINE DURING THE 3-DAY PRE-EXPERIMENTAL AND 30-DAY EXPERIMENTAL PERIODS

Item	Treatment			
	Pre-experimental	Experimental		
		"Low"	"Medium"	"High"
Urinary potassium				
mEq per day	53.74	9.26	25.78	51.03
% of intake	-----	$68.61^{A,a}$	$45.99^{B,b}$	$54.0^{A,B,b}$
Fecal potassium				
mEq per day	24.04	7.39	16.69	26.55
% of intake	-----	53.83^{A}	26.73^{B}	28.12^{B}
Urinary sodium				
mEq per day	48.14	45.36	46.07	35.58
% of intake	-----	$73.26^{A,a}$	$51.46^{B,b}$	$39.75^{B,c}$
Fecal sodium				
mEq per day	23.97	10.51	12.91	24.74
% of intake	-----	16.90^{a}	14.42^{a}	27.60^{b}
Urinary Nitrogen				
g per day	10.92	8.68	10.95	10.97
Fecal Nitrogen				
g per day	4.54	2.32	3.63	3.90

[A,B] Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.01$)

[a,b,c] Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

The data indicate that under conditions of this experiment the "medium" treatment level of potassium (2.2 g per day) is greater than the potassium maintenance requirement of wether lambs and the low treatment level (0.7 g per day) is inadequate. This is somewhat in agreement with Devlin and Roberts (16) who suggested that the maintenance requirement of wether lambs is approximately 1.19 g potassium daily. In addition, Telle et al. (41) reported the potassium maintenance level to be close to 65 mg potassium per kg body weight, which would be 2.23 g per day for the lambs used in this experiment.

Sodium. Sodium balance is illustrated in figure 4. All twelve lambs exhibited positive balances over the 30-day period, although the balance was significantly ($P < 0.01$) less positive in the "low" treatment group. The "low" potassium lambs retained 199.90 mEq sodium over the 30-day period while the "medium" and "high" potassium lambs retained 916.88 and 876.94 mEq, respectively. This difference can be attributed partially to the poor appetite of the "low" potassium lambs. Despite the care taken to maintain an equivalent sodium intake the "low" potassium lambs consumed only approximately three-fourths as much sodium as the other treatment groups (1876.23 mEq compared with 2699.5 mEq sodium, respectively).

An illustration of urinary and fecal excretion of

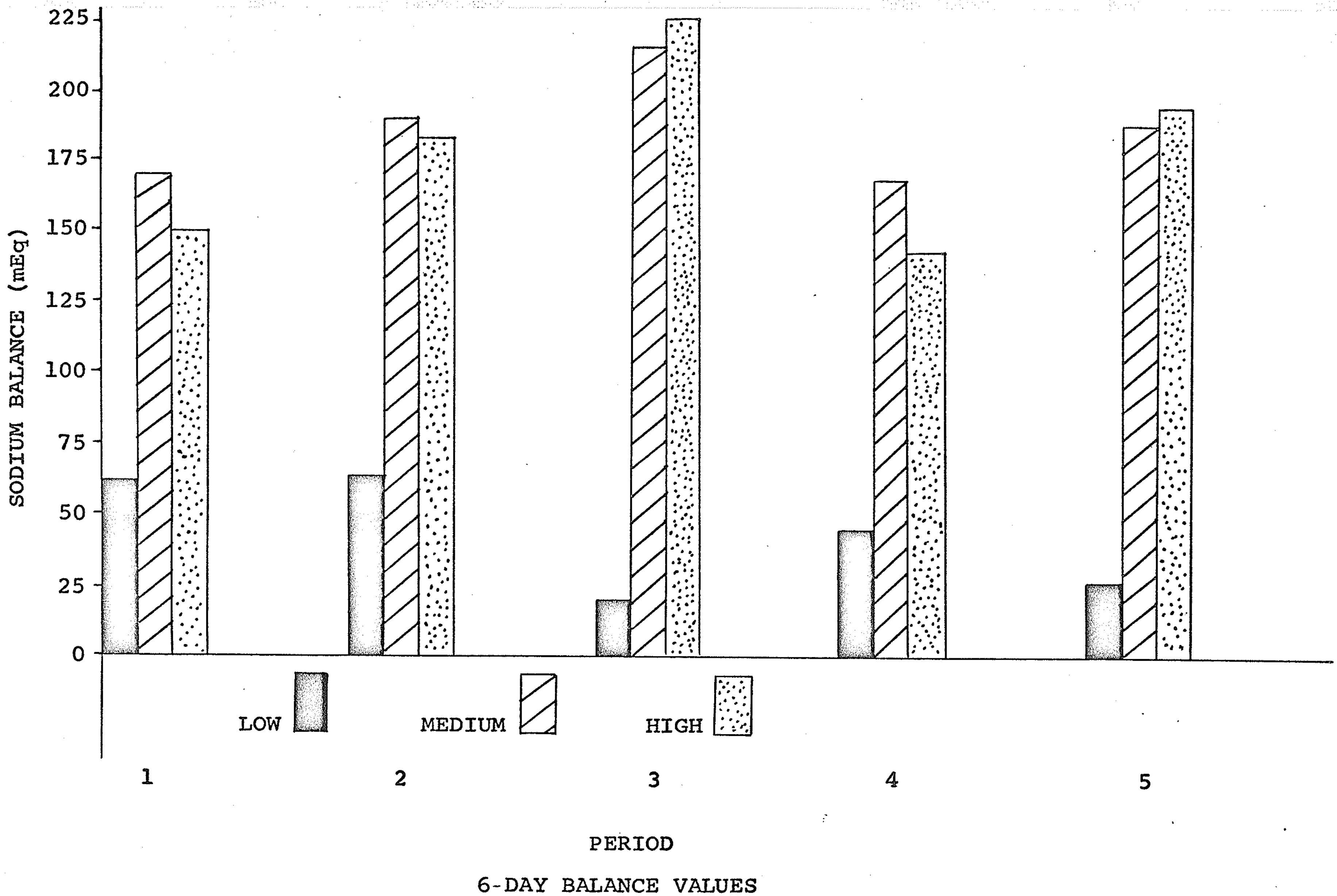


Figure 4. The influence of potassium intake upon apparent sodium balance of lambs receiving 0.7 (low), 2.2 (medium) and 3.7 (high) g potassium daily.

sodium as affected by potassium intake is presented in figure 5. Average daily urinary sodium excretion by the "low", "medium" and "high" treatments was 45.36, 46.07 and 35.58 mEq, respectively (table 6). These values when expressed as a per cent of intake were all significantly ($P < 0.05$) different. Thus it appears that the level of potassium in the ration has an effect on the ability of the kidney to conserve sodium. As potassium is secreted in exchange for sodium reabsorption in the kidney tubules, the low potassium intake may alter this relationship causing an increased excretion of sodium. However, the lower urinary sodium excretion by the "high" treatment lambs appears to be a consequence of poor net absorption from the gut. Average daily fecal sodium excretion for the "low", "medium" and "high" treatment groups was 10.51, 12.91 and 24.74 mEq, respectively (table 6). The "high" potassium lambs excreted significantly ($P < 0.05$) more sodium in the feces than the other two treatment groups. It appears that the high potassium intake was antagonistic to the net absorption of sodium. Devlin and Roberts (16) reported, on the other hand, that a low sodium ration caused a marked increase in fecal potassium excretion. Thus it appears that a definite relationship exists between ration levels of sodium and potassium in their effects on each other

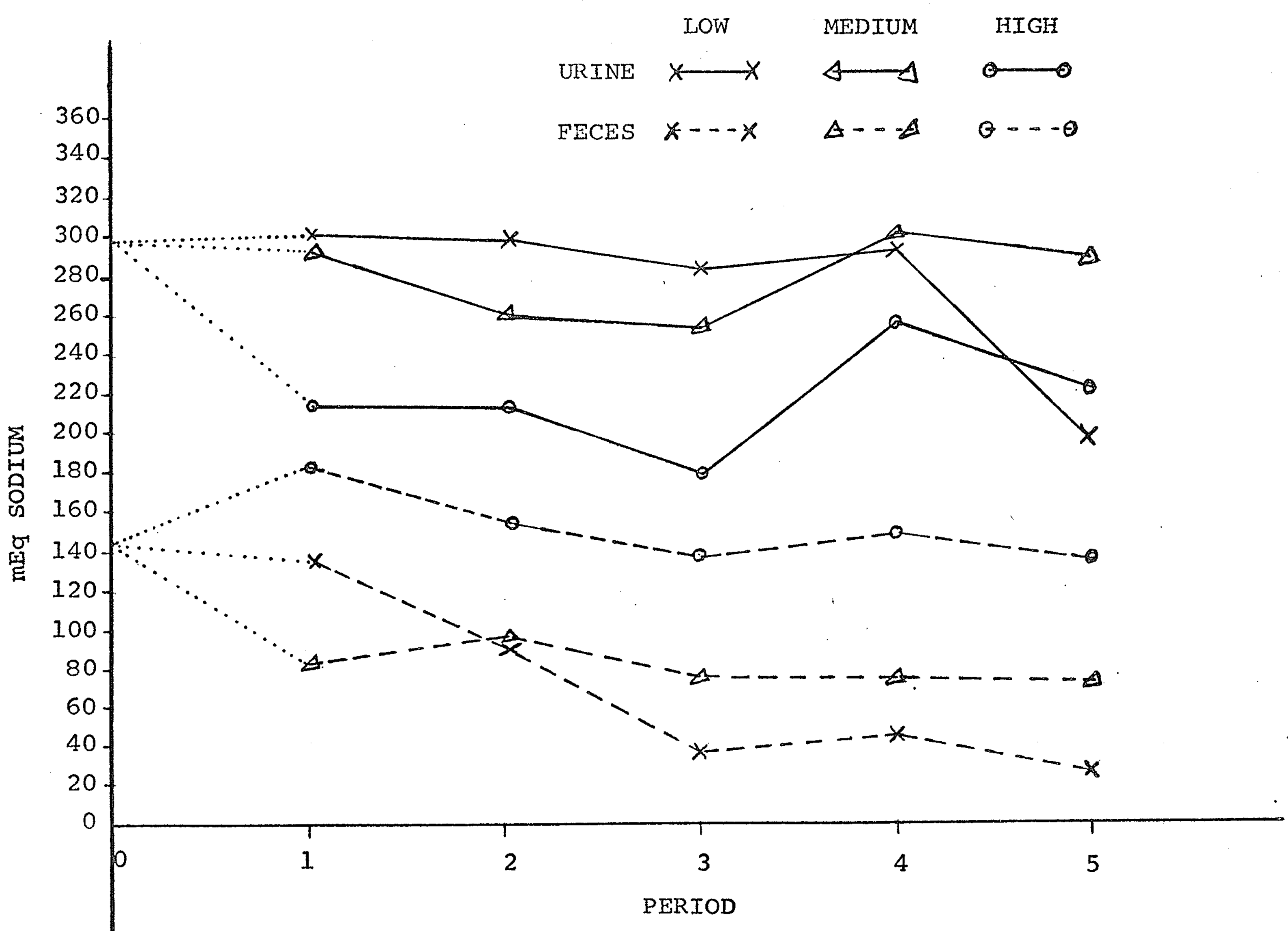


Figure 5. Average 6-day values for urinary and fecal sodium excretion.

with regard to absorption. Data from this present study indicate, that for a daily intake of 89.54 mEq sodium (2.1 g per day), the optimum potassium intake to promote maximum sodium absorption and consequently retention is 56.1 mEq per day (2.2 g per day).

Nitrogen. Average daily fecal and urinary nitrogen excretion are presented in table 6 and the average 6-day balance data is illustrated in figure 6. Two of the 4 lambs on "low" potassium were in negative nitrogen balance and the remaining two were in positive balance. The 30-day balance values for the 4 lambs were -4.1, -8.6, 38.5 and 44.7 g nitrogen. The lambs on "medium" and "high" potassium were all in positive nitrogen balance with average 30-day retentions of 129.3 and 120.7 g, respectively. Although the latter two treatment groups retained significantly ($P<0.05$) more nitrogen than the "low" treatment groups, it is difficult to ascertain whether this was a potassium effect or simply due to a marked reduction in nitrogen intake, or a combination of both. Other workers have reported potassium deficiency to be associated with a decreased nitrogen utilization as indicated by less nitrogen retention than control animals (11, 35).

Urinary urea, ammonia and creatinine values are presented in table 7. The method of collection allowed the

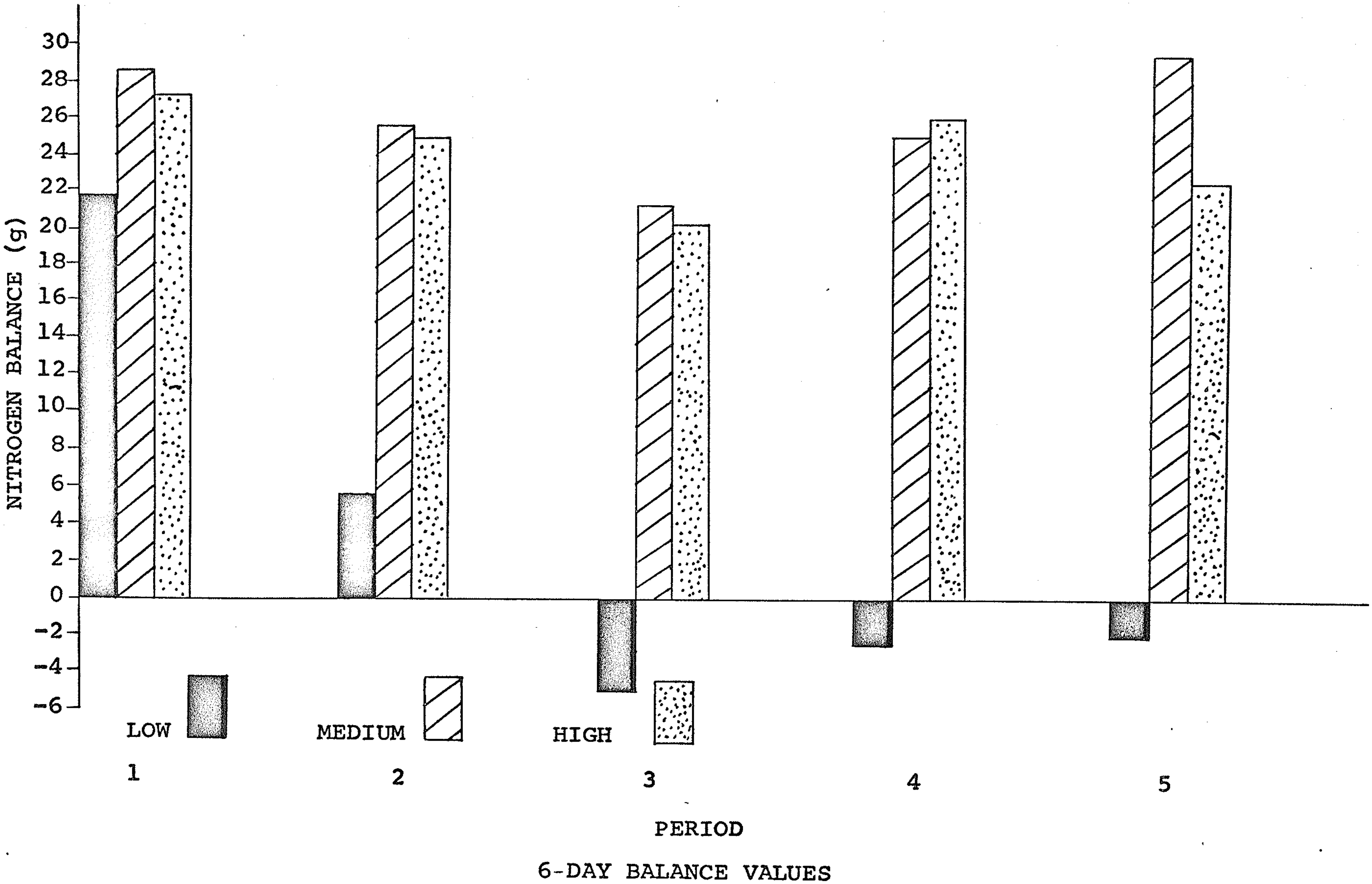


Figure 6. The influence of potassium intake upon apparent nitrogen balance of lambs receiving 0.7 (low), 2.2 (medium) and 3.7 (high) g potassium daily.

TABLE 7 EXPERIMENT II

THE EFFECT OF RATION POTASSIUM LEVEL UPON URINARY EXCRETION[1] OF UREA, AMMONIA AND CREATININE

	Treatment		
Item	"Low"	"Medium"	"High"
Ammonia	42.97	40.88*	47.86*
Urea	207.22	272.13*	264.18*
Creatinine	8.46	8.30	8.41*

[1]Expressed as g per 30 days
*Average of 3 lambs

urine to come in contact with the body of the sheep if it did not pass directly into the collection jar immediately after being voided. This could possibly result in considerable microbial activity and the subsequent conversion of urine urea to ammonia. The ammonia values obtained are higher than literature values which could suggest that this conversion may have been occurring. Urine ammonia concentration has been shown to increase during potassium deficiency (43). However, in this study, no significant treatment effects were revealed with regard to ammonia excretion. Similarly, urine creatinine and urea concentrations showed no treatment differences. The average creatinine excretions for the "low", "medium" and "high" treatment groups were 8.47, 8.30 and 8.41 g per 30 days, respectively.

Rumen Fluid Analysis. Rumen fluid data is presented in table 8. The average pH's for the "low", "medium" and "high" treatment groups were 6.31, 6.67 and 6.72, respectively. The average rumen pH of the "low" treatment group was significantly ($P < 0.05$) lower than values for the other two treatment groups. This finding is similar to the results reported in Experiments Ia and Ib. Telle *et al.* (41) measured the pH of rations containing various levels of potassium (from 0.1 to 0.62% potassium) and reported a range of pH values from 5.5 to 8.6. Therefore, it appears that by increasing the

TABLE 8 EXPERIMENT II

THE EFFECT OF RATION POTASSIUM LEVEL UPON pH AND MICROBIAL ACTIVITY OF RUMEN CONTENTS AND SODIUM AND POTASSIUM CONCENTRATION IN RUMEN FLUID

	Treatment		
Item	"Low"	"Medium"	"High"
pH	6.31^{a}	6.67^{b}	6.72^{b}
Microbial activity[1]	38.1	66.7	66.5
Sodium, mEq/ml	$.064^{A}$	$.111^{B}$	$.109^{B}$
Potassium, mEq/ml	.042	.025	.026

[1]Expressed as change in mm Hg per g dry matter per 2 hr

[A,B]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.01$)

[a,b]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

ration levels of K_2CO_3 the pH of feed as well as the rumen contents will be increased.

Microbial activity of rumen samples obtained from the "medium" and "high" treatment lambs were quite similar with average values of 66.7 and 66.5 mm Hg per g dry matter per 2 hours, respectively. The average value for the "low" treatment group was 38.1 mm Hg. This latter value was not significantly lower ($P > 0.05$) due to a wide variation within the treatment group. The rumen samples were collected approximately 90 minutes after feeding in order to obtain a comparable estimate of microbial activity. However, due to poor appetite of the "low" treatment lambs less feed was consumed prior to obtaining rumen samples, which in turn may have been partially responsible for the lower estimate of microbial activity in these lambs. Conversely, this decrease in rumen microbial activity of the "low" treatment group may have been partially responsible for the poor appetite of these lambs. Judging from the results of Experiments Ia and Ib, where appetite was found not to be mediated via the microbial population, the lower activity values of the "low" treatment lambs in this experiment were probably due to the marked decrease in feed consumption.

The rumen sodium and potassium concentrations are of interest in that the "low" treatment group showed a non-significant ($P > 0.05$) increase in potassium concentration when compared with the "medium" and "high" treatment groups. In contrast to this the sodium concentration of the "low" treatment rumen fluid was significantly ($P < 0.01$) lower than the other two groups. The average rumen potassium concentrations for the "low", "medium" and "high" treatment groups were 0.042, 0.025 and 0.026 mEq per ml of rumen fluid, respectively. Similar values for sodium were "low" 0.064, "medium" 0.111, and "high" 0.109 mEq per ml rumen fluid. A net influx or just simply poorer absorption from the rumen was evident in the "low" treatment group, because the rumen fluid potassium concentration was greater than either the "medium" or the "high" treatment groups. The high ratio of mineral to basal ration fed in the "low" treatment group may be a partial explanation for this higher rumen potassium concentration. However, if this was the case, rumen sodium concentration should also have been greater, which was not observed. Telle _et al._ (41) observed lower potassium concentrations in rumen fluid of sheep receiving a 0.32% potassium ration than in sheep receiving 0.50 and 0.62% potassium rations. However, these sheep were not consuming rations as low in potassium as the lambs in this experiment. Similarly, the results of Experiments Ia and Ib did not reveal increased rumen potassium concentrations when a relatively low quantity of potassium was in the feed, but rather the converse of this. Again these animals were not depleted of potassium to the same degree as the lambs in Experiment II.

Ration Digestibility. No statistical ($P > 0.05$) differences were observed among treatment groups with regard to apparent energy and dry matter digestibility. Dry matter and energy digestibilities are presented in table 9. Average energy digestion coefficients for the "low", "medium" and "high" treatment groups were 70.74, 69.29 and 71.16, respectively. The corresponding values for dry matter digestibility were "low" 67.72, "medium" 66.73 and "high" 67.96. The average dry matter digestibility was approximately 3 digestion units less than the corresponding energy digestibility. This may be accounted for by the high content of fat in the ration. Apparent nitrogen digestibility values are presented in table 9 and no significant difference among treatments was observed. The average digestion coefficients for nitrogen were 79.81, 80.78 and 79.35 for the "low", "medium" and "high" groups, respectively. These data indicate that ration potassium level has little effect upon ration digestibility.

TABLE 9 EXPERIMENT II

THE EFFECT OF RATION POTASSIUM LEVEL UPON APPARENT ENERGY, DRY MATTER AND NITROGEN DIGESTIBILITY, VARIOUS SERUM COMPONENTS, AND NON-SCOURED WOOL POTASSIUM AND SODIUM CONCENTRATIONS

	Treatment		
Item	"Low"	"Medium"	"High"
Energy digestibility, %	70.74	69.29	71.16
Dry matter digestibility, %	67.72	66.73	67.96
Nitrogen digestibility, %	79.81	80.78	79.35
Serum potassium, mEq/l	3.54[a]	4.59[b]	4.73[b]
Serum sodium, mEq/l	141.4	148.4	148.4
Serum chloride, mEq/l	113.5	111.3	111.3
Non-scoured wool potassium, mg/g	64.2	45.9	56.2
Non-scoured wool sodium, mg/g	1.53	1.45	1.61

[a,b]Treatment means within an item not showing the same superscript letter are significantly different ($P < 0.05$)

Serum and Wool Analyses. The serum potassium concentration of the "low" treatment lambs was significantly ($P < 0.05$) lower than the other two treatments. However, no significant ($P > 0.05$) differences were found in the serum sodium and chloride concentrations (table 9). Considerable variation within treatments was observed with regard to the potassium concentration of the non-scoured wool samples. The potassium concentrations were 64.2, 45.9 and 56.2 mg per g of non-scoured wool, for the "low", "medium" and "high treatment lambs, respectively. Less sodium was found in the non-scoured wool with average concentrations of "low" 1.53, "medium" 1.45, and "high" 1.61 mg per g. These data indicate that a considerable quantity of potassium and a lesser amount of sodium are excreted by way of the skin in sheep. This additional loss must be considered when determining the true balance of these minerals.

Raw data and a list of mean squares illustrating the statistical analyses are presented in the appendix.

SUMMARY

A 56-day feeding trial, followed by a paired feeding trial and an appetite trial, was conducted utilizing 64 western range wether lambs. In addition, replicate 30-day balance trials were carried out with 12 lambs. The levels of potassium fed were 0.1, 0.3, 0.5 and 0.7% of the ration in the feeding trials and "low" 0.7, "medium" 2.2, and "high" 3.7 g per day in the balance trials.

Data collected indicate the following:

(1) The level of potassium in the ration required to produce optimum feedlot performance by the lambs was between 0.3 and 0.5% of the air dry ration.

(2) Potassium had a marked effect on appetite as average daily feed consumption for the 0.1, 0.3, 0.5 and 0.7% potassium lambs was 0.84, 1.92, 2.64 and 2.71 lb per day, respectively. The appetite response was evident in the 0.1% lambs within two days of the initiation of the trial.

(3) Potassium had an effect on growth as the pair fed 0.7% potassium lambs gained significantly ($P < 0.05$) more weight than the 0.3% potassium lambs.

(4) Serum concentrations of potassium, phosphorus and calcium were significantly ($P < 0.05$) affected by level of potassium in the ration. However, no significant ($P > 0.05$) differences in serum concentrations of sodium, magnesium or

chloride were apparent.

(5) A considerable loss of potassium occurred by way of the skin, as indicated by non-scoured wool potassium analysis, and this loss appeared to increase as the level of potassium in the ration was increased.

(6) Potassium deficient lambs revealed a decrease in potassium concentration of heart and skeletal muscle. The cellular loss of potassium in the skeletal muscle was partially compensated for by an increase in sodium concentration. On the other hand, sodium concentration of the heart was significantly ($P<0.05$) decreased in the depleted animals. Liver potassium levels revealed a significant ($P<0.05$) increase when deficient lambs were compared with controls. Potassium depletion had little effect on liver sodium concentration or kidney sodium and potassium concentrations.

(7) An autopsy of potassium deficient lambs revealed no gross abnormalities. In addition, histological observations indicated little effect of potassium depletion on the heart, adrenal glands or intestine. However, the kidney was markedly affected by potassium depletion. Hyperplastic lesions and eosinophilic cytoplasmic granules were observed in the tubular area of the kidney. Interstitial fibrosis and cloudy swelling of the tubules were also noticed

in the slides prepared from the sections obtained from the kidneys of the 0.1% potassium lambs.

(8) An apparent negative balance occurred in the "low" potassium lambs resulting in a net loss of potassium over the 30-day period. Positive potassium balances and slight increases in body weight were apparent in the "medium" and "high" treatment lambs indicating the maintenance requirement to be slightly less than 2.2 g potassium per day.

(9) The "low", "medium" and "high" potassium lambs revealed an apparent positive sodium balance; however, the "medium" and "high" potassium lambs retained significantly more sodium over the 30-day period than the "low" potassium lambs. The "low" potassium lambs excreted significantly ($P < 0.01$) more sodium (expressed as a % of intake) in the urine than the "medium" potassium lambs which in turn excreted significantly ($P < 0.05$) more than the "high" potassium lambs. Fecal excretion of sodium was significantly ($P < 0.01$) greater for the "high" potassium lambs than for the "medium" or "low" potassium lambs. Thus it appears that the "low" potassium intake decreased the ability of the lambs to conserve sodium and, in addition, a poorer net absorption of sodium resulted when the "high" level of potassium was fed.

(10) Nitrogen balance was less positive for the

"low" potassium lambs than for the "medium" and "high" potassium lambs. Urinary excretion of ammonia, urea and creatinine was similar in the "low", "medium" and "high" treatment groups.

(11) The microbial activity of rumen contents, as measured by an *in vitro* technique, indicated that the appetite effect caused by the low level of potassium in the ration was not mediated via the microorganisms.

(12) Level of potassium in the ration had no significant ($P > 0.05$) effect on either apparent dry matter, energy or nitrogen digestibility.

(13) Daily water consumption of the "low", "medium" and "high" potassium lambs was not affected by potassium intake.

BIBLIOGRAPHY

1. Ashford, C. A. and K. C. Dixon. 1935. The effect of potassium on the glycolysis of brain tissue with reference to the potassium effect. Biochem. J. 29:157.

2. Association of Official Agricultural Chemists. 1960. Official Methods of Analysis. 9th Edition.

3. Bell, J. M. and J. D. Eirfle. 1958. The requirement for potassium in the diet of the growing mouse. Can. J. Animal Sci. 35:145.

4. Berry, J. W., D. S. Chappell and R. B. Barnes. 1946. Improved method of flame photometry. Ind. Eng. Chem. Anal. Ed., 18:19.

5. Biggs, H. G. and J. M. Cooper. 1961. Modified Folin methods for measurement of urinary creatine and creatinine. Clin. Chem. 7(6):655.

6. Black, D. A. K. 1960. Current concepts of potassium metabolism. J. Pediat. 56:814.

7. Bladh, W. H. and S. H. Bessett. 1953. Prolonged potassium deficiency in man. Metabolism 2:218.

8. Brink, M. R. 1962. Potassium requirement of the immature ovine. Dissertation abst. 22(8):2534.

9. Burnell, J. M. and B. H. Scribner. 1957. Serum potassium concentration as guide to potassium need. J. A. M. A. 164:959.

10. Burns, R. H., A. Johnston, J. W. Hamilton, R. J. McColloch, W. E. Duncan and H. G. Fisk. 1964. Minerals in domestic wools. J. Animal Sci. 23:5.

11. Cannon, P. R., L. E. Frazier and R. H. Huges. 1952. Influence of potassium on tissue protein synthesis. Metabolism 1:49.

12. Cannon, P. R., L. E. Frazier and R. H. Huges. 1953. Sodium as a toxic ion in potassium deficiency. Metabolism 2:297.

13. Clark, R. 1959. A study of the plasma sodium and potassium levels in normal Merino sheep. Onderstepoort J. Vet. Res. 28(2):229.

14. Cooke, R. E., W. E., Segar, D. B. Cheek, F. E. Coville and D. C. Darrow. 1952. The extra renal correction of alkalosis associated with potassium deficiency. J. Clin. Invest. 31:798.

15. Darrow, D. C. and H. C. Miller. 1942. The production of cardiac lesions by repeated injections of desoxycorticosterone acetate, J. Clin. Invest. 21:601.

16. Devlin, T. J. and W. K. Roberts. 1963. Dietary maintenance requirement of sodium for wether lambs. J. An. Sci. 22:648.

17. Dobson, A. 1961. Absorption from the rumen. Digestive Physiology and Nutrition of the Ruminant. D. Lewis, Butterworths, London.

18. Du Toit, P. S., A. I. Malan and J. W. Greenwald. 1934. Studies in mineral metabolism. XXXI Minimum mineral requirements of cattle. Onderstepoort J. 2:565.

19. Eckel, R. E., J. E. C. Norris and C. E. Pope. 1958. Basic amino acids as intracellular cations in potassium deficiency. Amer. J. Physiol. 193:644.

20. Fenn, W. O. 1939. The deposition of potassium and phosphate with glycogen in rat livers. J. Biol. Chem. 128:297.

21. Fister, H. J. 1950. Manual of Standardized Procedures for Spectrophotometric Chemistry. C-10a. Standard Scientific Supply Corp. New York.

22. Fuhrman, F. A. 1951. Gycogen, glucose tolerance and tissue metabolism in potassium deficient rats. Amer. J. Physiol. 167:314.

23. Gardner, L. I., N. B. Talbot, C. D. Cook, H. Berman and C. Uribe. 1950. The effect of potassium deficiency on carbohydrate metabolism. J. Lab. and Clin. Med. 35:592.

24. Graw, C. R., F. H. Fratzer and W. E. Newlon. 1956. Principles of nutrition for chickens and turkeys. Circ. 450, Calif. Agr. Expt. Sta.

25. Greaves, J. E., E. J. Maynard and W. Reeder. 1934. Influence of calcium and phosphorus intake on bovine blood. J. Agr. Research 48:1033.

26. Harrison, K. 1954. A review of the metabolism of potassium. Med. J. Austral. 1:285.

27. Hawk, P. B., B. L. Oser and W. H. Summerson. 1954. Practical Physiological Chemistry. 13th Edition. J. & A. Churchill, Ltd. London.

28. Hubbert, F. Jr., E. Cheng and W. Burroughs. 1958. The influence of potassium, sodium, rubidium, lithium and cesium on in vitro cellulose digestion by rumen microorganisms with observations upon sodium and potassium influences in lamb fattening rations. J. Animal Sci. 17:576.

29. Hungate, R. E., D. W. Fletcher, R. W. Dougherty and B. F. Barrentine. 1955. Microbial activity in the bovine rumen: Its measurements and relation to bloat. Appl. Microbiol. 3:161.

30. Jensen, A. H., S. W. Terrill and D. E. Beachu. 1961. Response of young pigs to levels of dietary potassium. J. Animal Sci. 20:464.

31. Kornberg, A. and K. M. Endicott. 1946. Potassium deficiency in the rat. Amer. J. Physiol. 145:291.

32. Maynard, L. A. and J. K. Loosli. 1956. Animal Nutrition. 4th Edition. McGraw-Hill Book Company, Inc. New York.

33. Meyer, J. H., R. R. Grunert, M. T. Zepplin, R. H. Grummer, R. H. Bobstedt and P. H. Phillips. 1950. Effect of dietary levels of sodium and potassium on growth and on concentration in blood plasma and tissues of white rat. Amer. J. Physiol. 162:182.

34. Miller, H. C. 1923. Potassium in animal nutrition. II Potassium in its relation to growth of young rats. J. Biol. Chem., 55:61.

35. Muntwyler, E., G. E. Griffin and R. L. Arends. 1953. Muscle electrolyte composition and balances of nitrogen and potassium in potassium deficient rats. Amer. J. Physiol. 174:283.

36. Orent-Keiles, E. and E. V. McCollum. 1941. Potassium in animal nutrition. J. Biol. Chem. 140:337.

37. Pearse, A. G. E. and C. R. MacPherson. 1958. Renal histochemistry in potassium depletion. J. Path. and Bact. 75:69.

38. Schales, O. and S. S. Schales. 1941. A simple and accurate method for the determination of chloride in biochemical fluids. J. Biol. Chem. 140:879.

39. Steel, R. G. D. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc. New York.

40. Sullivan, T. W. 1963. Studies on the potassium requirement of turkeys to four weeks of age. Poultry Sci. 42:1072.

41. Telle, P. P., R. L. Preston, L. D. Kinter and W. H. Pfander. 1964. Definition of the ovine potassium requirements. J. Animal Sci. 23:59.

42. Walser, W. 1960. Determination of free magnesium ions in body fluids. Anal. Chem. 32:711.

43. Welt, L. G., W. Hollander, Jr. and W. B. Blythe. 1960. The consequences of potassium depletion. J. Chron. Dis. 11:213.

44. Wise, M. B., R. A. Wentwarth and S. E. Smith. 1961. Availability of the phosphorus in various sources for calves. J. Animal Sci. 20(2):329.

APPENDIX

TABLE 10 EXPERIMENT Ia

MEAN SQUARES FOR WEIGHT GAINS AND SERUM COMPONENTS

Item		
Source of variation	Treatment	Error
Degrees of freedom	3	28
	(Mean squares)	
Weight gains	4,673.9**	64.3[1]
Potassium	4.04**	0.22
Sodium	62.0	23.9[2]
Calcium	1.77	0.87
Magnesium	0.43	0.17
Phosphorus	16.8**	1.7
Chloride	30.8	24.6

*($P < 0.05$)
**($P < 0.01$)
[1]Error degrees of freedom 57
[2]Error degrees of freedom 25

TABLE 11 EXPERIMENT Ib

MEAN SQUARES FOR WEIGHT GAINS AND SERUM COMPONENTS

Item			
Source of variation	Treatments	Periods	Error
Degrees of freedom	1	1	15
		(Mean squares)	
Weight gains	123.4*	-----	20.2[1]
Potassium	4.74**	3.06**	0.14
Calcium	4.67*	0.20	0.76
Magnesium	0.10	0.003	0.47
Phosphorus	9.3	1.3	2.4
Sodium	81.6*	33.0	16.8
Chloride	20.8	15.7	33.4

*(P<0.01)
**(P<0.05)
[1]Error degrees of freedom 7

TABLE 12 EXPERIMENT II

MEAN SQUARES FOR THE VARIOUS MEASUREMENTS MADE IN EXPERIMENT II

Item				
Source of variation	Treatments	Blocks	Interaction	Error
Degrees of freedom	2	1	2	6
		(Mean squares)		
Potassium balance	435,049.2**	13.74	27,047.5*	3,912.77
Sodium balance	651,868.4**	16,652.0	8,735.0	9,614.0
Nitrogen balance	15,460.3*	221.9	267.8	749.5
Urinary potassium	525.7*	78.3	191.7	54.6
Urinary sodium	1,156.7**	245.8*	35.6	25.2
Fecal potassium	936.5*	9.8	180.1	93.1
Fecal sodium	196.1*	126.9	43.1	24.0
Water consumption	119.3	922.3	78.3	278.4
Urinary urea and ammonia	12.1	1.8	2.1	10.6
Energy digestibility	3.8	65.9*	0.1	10.2
Dry matter digestibility	1.7	67.7*	1.8	6.7
Nitrogen digestibility	2.1	8.6*	2.0	0.8
Av weight change	243.3**	1.0	16.7	8.1
Serum potassium	1.7*	0.9	0.3	0.2
Serum sodium	67.3	2.6	55.7	18.6
Serum chloride	6.5	0.4	24.5*	4.5

*($P < 0.05$)
**($P < 0.01$)

TABLE 13 EXPERIMENTS Ia, Ib AND II

MICROBIAL ACTIVITY AND pH OF RUMEN CONTENTS AND POTASSIUM AND SODIUM CONCENTRATIONS OF RUMEN FLUID

Sheep No	Treatment	Microbial activity[1]	pH	Potassium[2]	Sodium[2]
Experiment Ia					
27	.3% K	19.9	6.64	.016	.122
108	.3% K	11.1	6.58	.014	.093
149	.3% K	31.0	6.16	.020	.104
154	.3% K	40.1	6.22	.018	.086
22	.7% K	10.7	6.72	.027	.115
146	.7% K	13.4	6.63	.022	.101
74	.7% K	18.0	6.25	.028	.083
49	.7% K	26.3	6.20	.032	.126
Experiment Ib					
40	.3% K	32.7	6.85	.026	.098
20	.3% K	56.3	6.76	.023	.115
151	.7% K	21.8	6.97	.026	.101
34	.7% K	25.0	6.83	.030	.116
Experiment II					
94	"Low"	52.7	5.96	.039	.059
138	"Low"	38.0	6.39	.025	.062
35	"Low"	23.5	6.56	.063	.070
78	"Medium"	63.2	6.43	.028	.102
38	"Medium"	63.4	6.74	.027	.115
10	"Medium"	57.5	6.68	.022	.102
50	"Medium"	82.9	6.83	.023	.127
4	"High"	64.2	6.64	.021	.094
31	"High"	52.5	6.73	.031	.126
144	"High"	59.2	6.70	.025	.109
39	"High"	90.3	6.82	.025	.109

[1]Expressed as mm Hg per g dry matter per 2 hr

[2]Expressed as mEq per ml rumen fluid

TABLE 14 EXPERIMENT II

FEED CONSUMPTION, POTASSIUM INTAKE, FECAL POTASSIUM, URINARY POTASSIUM, SODIUM INTAKE, FECAL SODIUM, URINARY SODIUM, NITROGEN INTAKE, FECAL NITROGEN, URINARY NITROGEN AND WATER INTAKE OF SHEEP ON THE "LOW" POTASSIUM RATION

	Period					
Sheep No	0[1]	1[2]	2[2]	3[2]	4[2]	5[2]
			Feed consumption (g)			
94	1800	2570	1609	1417	1882	1163
138	1800	3346	2065	2524	1880	3021
35	1800	3420	3123	1334	449	550
46	1800	3420	2530	1920	1885	1015
			Potassium intake (mEq)			
94	282.4	77.4	79.5	69.6	97.6	77.6
138	282.4	100.1	92.7	91.5	99.3	97.8
35	284.1	108.0	98.9	71.3	26.3	30.3
46	284.1	108.0	104.4	82.2	101.3	33.7
			Fecal potassium (mEq)			
94	88.2	131.7	43.5	28.3	25.4	15.6
138	76.0	109.6	53.1	42.9	48.1	43.6
35	37.0	61.4	72.9	25.4	10.5	16.2
46	31.9	43.7	42.6	36.4	20.4	16.1
			Urinary potassium (mEq)			
94	182.4	63.2	31.9	28.1	60.6	61.7
138	133.0	75.3	29.1	34.9	90.0	35.5
35	222.4	96.8	44.7	36.5	38.0	57.4
46	167.6	73.2	41.2	34.5	74.9	103.5
			Sodium intake (mEq)			
94	269.9	399.9	371.1	206.6	427.5	274.6
138	269.9	501.5	412.2	440.8	472.4	439.6
35	267.3	534.6	482.5	273.6	114.6	91.1
46	267.3	534.6	500.4	411.1	469.7	146.5
			Fecal sodium (mEq)			
94	150.2	182.9	66.1	40.2	32.3	11.8
138	106.7	175.0	122.7	61.3	78.8	51.1
35	62.8	110.3	87.4	9.7	48.6	9.4
46	49.9	57.5	61.7	24.5	13.4	17.5

TABLE 14 (continued)

			Urinary sodium (mEq)			
94	141.9	187.3	277.4	216.3	352.4	160.6
138	87.3	332.1	271.9	283.3	257.5	237.0
35	171.8	336.5	324.0	261.3	159.1	115.7
46	227.1	343.6	308.6	363.8	395.9	258.9
			Nitrogen intake (g)			
94	56.7	86.7	54.3	49.0	62.3	39.5
138	56.7	110.9	68.7	83.0	62.4	99.9
35	56.7	113.4	104.2	46.0	19.1	24.2
46	56.7	113.4	86.6	64.9	62.5	37.4
			Fecal nitrogen (g)			
94	14.1	21.5	9.1	9.6	10.6	8.5
138	12.7	20.9	13.5	13.3	12.3	15.6
35	12.5	22.1	20.6	11.7	6.0	5.4
46	12.7	21.4	19.7	14.2	12.2	9.7
			Urinary nitrogen (g)			
94	43.8	67.3	42.8	45.2	42.1	39.2
138	35.1	69.7	66.6	64.3	54.1	57.0
35	34.0	61.7	66.1	53.2	32.1	36.8
46	27.5	52.8	54.7	52.0	46.5	36.9
			Water intake (l)			
94	6.5	12.0	8.5	7.8	8.8	5.9
138	7.8	10.9	15.0	18.0	12.0	13.6
35	4.0	7.8	9.0	5.0	1.3	3.2
46	6.0	7.7	8.8	6.9	6.2	5.0

[1] 3-day pre-experimental period

[2] 6-day experimental period

TABLE 15 EXPERIMENT II

FEED CONSUMPTION, POTASSIUM INTAKE, FECAL POTASSIUM, URINARY POTASSIUM, SODIUM INTAKE, FECAL SODIUM, URINARY SODIUM, NITROGEN INTAKE, FECAL NITROGEN, URINARY NITROGEN AND WATER INTAKE OF SHEEP ON THE "MEDIUM" POTASSIUM RATION

	Period					
Sheep No	0[1]	1[2]	2[2]	3[2]	4[2]	5[2]
	Feed consumption (g)					
78	1800	3600	3600	3600	3600	3600
38	1800	3600	3600	3600	3600	3600
10	1800	3600	3600	3600	3600	3600
50	1800	3600	3600	3600	3600	3600
	Potassium intake (mEq)					
78	282.4	334.6	334.6	334.6	334.6	334.6
38	282.4	334.6	334.6	334.6	334.6	334.6
10	284.1	338.1	338.1	338.1	338.1	338.1
50	284.1	338.1	338.1	338.1	338.1	338.1
	Fecal potassium (mEq)					
78	55.8	49.1	94.3	94.4	70.0	76.1
38	34.4	53.0	97.9	56.8	54.4	49.8
10	81.2	176.7	155.5	154.9	121.9	134.7
50	41.2	85.3	93.9	78.5	53.3	49.9
	Urinary potassium (mEq)					
78	188.1	205.0	145.6	126.2	145.3	123.7
38	181.4	180.0	137.7	183.2	171.7	159.2
10	152.0	116.2	75.4	129.4	140.0	128.7
50	200.2	194.1	173.0	200.7	164.3	196.2
	Sodium intake (mEq)					
78	269.9	539.9	539.9	539.9	539.9	539.9
38	269.9	539.9	539.9	539.9	539.9	539.9
10	267.3	534.6	534.6	534.6	534.6	534.6
50	267.3	534.6	534.6	534.6	534.6	534.6
	Fecal sodium (mEq)					
78	82.2	59.7	92.5	81.6	61.5	55.9
38	43.4	93.5	104.1	67.2	73.5	74.1
10	46.3	116.6	130.0	88.8	92.1	112.7
50	23.7	52.0	44.8	53.7	60.0	34.6

TABLE 15 (continued)

			Urinary sodium (mEq)			
78	121.4	296.9	265.9	233.4	289.4	255.2
38	151.3	274.3	225.9	317.9	280.8	267.0
10	262.0	234.5	259.4	204.3	298.4	250.2
50	157.2	350.3	281.6	248.9	326.4	368.2
			Nitrogen intake (g)			
78	56.7	113.4	113.4	113.4	113.4	113.4
38	56.7	113.4	113.4	113.4	113.4	113.4
10	56.7	113.4	113.4	113.4	113.4	113.4
50	56.7	113.4	113.4	113.4	113.4	113.4
			Fecal nitrogen (g)			
78	12.6	23.9	21.5	22.4	20.4	20.9
38	10.3	20.7	23.2	22.1	22.3	20.3
10	10.5	21.9	21.1	21.9	20.2	21.0
50	11.2	20.7	22.8	23.7	23.6	21.8
			Urinary nitrogen (g)			
78	17.6	57.0	65.7	63.0	64.3	52.7
38	39.7	72.1	70.1	71.6	72.4	66.4
10	33.1	61.1	60.4	72.5	66.8	64.3
50	32.1	61.6	66.7	71.6	64.8	69.3
			Water consumption			
78	6.2	10.7	13.4	11.4	9.8	8.7
38	4.0	6.0	7.5	6.0	8.0	6.0
10	5.0	8.0	9.0	10.9	7.9	7.2
50	3.0	5.3	6.5	6.0	5.3	5.0

[1] 3-day pre-experimental period

[2] 6-day experimental period

TABLE 16 EXPERIMENT II

FEED CONSUMPTION, POTASSIUM INTAKE, FECAL POTASSIUM, URINARY POTASSIUM, SODIUM INTAKE, FECAL SODIUM, URINARY SODIUM, NITROGEN INTAKE, FECAL NITROGEN, URINARY NITROGEN AND WATER INTAKE OF SHEEP ON THE "HIGH" POTASSIUM RATION

	Period					
Sheep No	0[1]	1[2]	2[2]	3[2]	4[2]	5[2]
			Feed consumption (g)			
4	1800	3600	3600	3600	3600	3600
31	1800	3600	3600	3600	3600	3600
144	1800	3600	3600	3600	3600	3600
39	1800	3600	3600	3600	3600	3600
			Potassium intake (mEq)			
4	282.4	564.8	564.8	564.8	564.8	564.8
31	282.4	564.8	564.8	564.8	564.8	564.8
144	284.1	568.3	568.3	568.3	568.3	568.3
39	284.1	568.3	568.3	568.3	568.3	568.3
			Fecal potassium (mEq)			
4	159.0	208.6	197.4	200.5	219.1	208.2
31	69.1	127.5	129.2	145.6	116.1	102.2
144	80.1	159.0	187.5	194.7	155.1	138.5
39	111.5	171.8	142.1	152.3	106.8	123.6
			Urinary potassium (mEq)			
4	86.2	329.1	239.7	257.0	278.2	292.4
31	151.7	336.4	354.6	313.3	364.0	388.1
144	144.2	260.4	309.2	327.0	270.8	345.1
39	111.5	171.8	142.1	152.3	106.8	123.6
			Sodium intake (mEq)			
4	269.9	539.9	539.9	539.9	539.9	539.9
31	269.9	539.9	539.9	539.9	539.9	539.9
144	267.3	534.6	534.6	534.6	534.6	534.6
39	267.3	534.6	534.6	534.6	534.6	534.6
			Fecal sodium (mEq)			
4	95.1	323.2	194.8	147.3	214.4	142.7
31	58.7	189.3	147.2	155.1	153.1	159.0
144	50.3	88.2	111.9	122.3	117.1	97.5
39	93.6	124.8	142.4	125.0	91.5	121.6

TABLE 16 (continued)

			Urinary sodium (mEq)			
4	52.8	199.2	152.5	166.5	135.2	193.8
31	56.3	194.8	205.8	202.4	245.3	179.7
144	184.9	193.7	238.2	187.3	291.4	265.4
39	119.0	250.7	237.2	152.1	344.5	233.6
			Nitrogen intake (g)			
4	56.7	113.4	113.4	113.4	113.4	113.4
31	56.7	113.4	113.4	113.4	113.4	113.4
144	56.7	113.4	113.4	113.4	113.4	113.4
39	56.7	113.4	113.4	113.4	113.4	113.4
			Fecal nitrogen (g)			
4	15.1	25.2	21.6	18.8	23.0	23.3
31	11.6	21.7	21.3	23.6	19.1	21.5
144	21.6	23.9	25.4	24.0	25.4	22.7
39	16.3	25.7	25.7	28.6	23.4	24.5
			Urinary nitrogen (g)			
4	41.0	71.8	73.1	74.7	76.5	71.9
31	31.7	66.5	64.5	67.7	64.8	69.5
144	25.6	55.2	63.9	70.3	58.5	67.4
39	31.9	56.3	60.0	63.6	59.4	61.2
			Water consumption (l)			
4	8.0	14.0	19.0	18.6	17.3	12.4
31	4.0	7.6	7.5	7.0	9.1	6.9
144	5.6	9.6	9.0	9.9	8.0	8.5
39	2.7	7.0	7.3	7.0	7.9	8.0

[1]3-day pre-experimental period

[2]6-day experimental period